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U.S. Department
of Transportation

**Urban Mass
Transportation
Administration**

Conductive Interference in Rapid Transit Signaling Systems

Volume II: Suggested Test Procedures

Transportation Systems Center
Cambridge, MA 02142

Final Report

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Holmstrom, F. Ross.

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16. Abstract

Methods for detecting and quantifying the levels of conductive electromagnetic interference produced by solid state rapid transit propulsion equipment and for determining the susceptibility of signaling systems to these emissions are presented. These methods include procedures for taking measurements in the field, in the laboratory and on track circuits.

As background, the mechanisms of conductive electromagnetic interference are described, as are audio-frequency track circuits and solid-state propulsion control. Recording and documentation procedures for applying these suggested test procedures are provided.

Appendix A contains definitions of terms and systems of units. Appendix B contains sample outputs of tests using inductive recommended practices.

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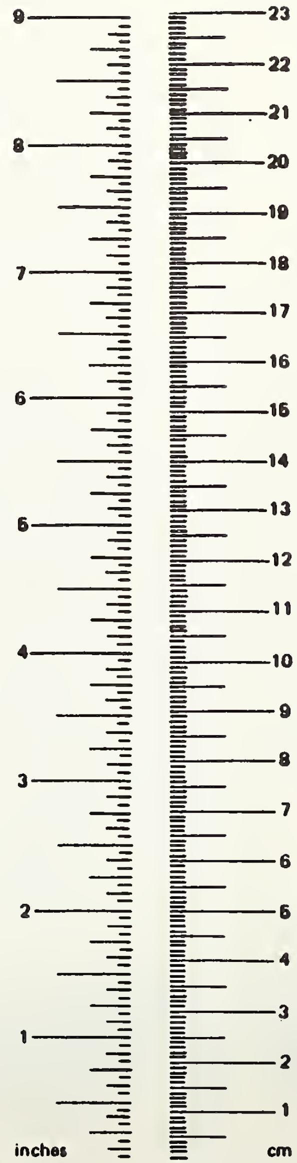
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

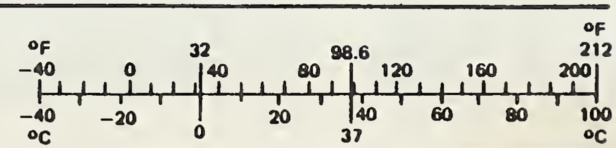
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

These suggested test procedures have been prepared by the Rail Transit Electromagnetic Interference and Compatibility (EMI/EMC) Technical Working Group (TWG) as part of a cooperative effort between the Federal Government -- the Urban Mass Transportation Administration (UMTA) and the Transportation Systems Center (TSC) of the U.S. Department of Transportation -- and the transit industry to develop standard methods of analysis and testing to quantify and resolve issues of electromagnetic compatibility (EMC) in rail transit operation.

This activity, over the past 7 years, has kept pace with the development of new propulsion and signaling techniques. To date, a number of suggested test procedures have been tested extensively and applied in the process of assuring compatibility between propulsion and signaling for a number of new and upgraded U.S. rail transit systems. The experience thus gained has been incorporated, along with suggestions and comments received from the rail transit operator and supply industries and their consultants, in preparing the finished versions of these suggested test procedures.

The suggested test procedures that have reached this final form address compatibility between rail transit propulsion systems and auxiliary power systems employing solid-state control of dc power, and signaling system track circuits. Solid-state control of propulsive and auxiliary power is characteristic of the types of equipment currently or soon to be available in new and upgraded U.S. rail transit systems.

The test procedures presented herein initially were developed to address compatibility of dc chopper propulsion control systems and audio-frequency (300 Hz-20 kHz) signaling systems. Since choppers operate at frequencies of 200 to 400 Hz, their harmonics cannot interfere with power-frequency (25-100 Hz) track circuits. However, since ac inverters sweep through frequencies used in both power-frequency and audio-frequency signaling, the test procedures have been extended to address compatibility of solid-state propulsion control systems with power-frequency signaling systems, and they have been applied successfully for this purpose.

Three salient types of electrical interference are dealt with in suggested test procedures developed by the TWG - conductive, inductive, and radiated. Radiated EMI has not been found to impact either power-frequency or audio-frequency signaling, but it poses a potential problem with radio and TV reception near surface rapid transit lines, and therefore warrants assessment.

These procedures are subject to change as improved methods and techniques are developed, and as more advanced equipment becomes available. The Standards and Foreign Practices Subcommittee of the Institute of Electrical and Electronic Engineers (IEEE) Land Transportation Committee has agreed to augment and update them periodically as required. The IEEE should be contacted in the future for up-to-date information on test procedures.

The Rail Transit EMI/EMC Technical Working Group includes representatives from the following manufacturers of rail transit equipment and industry consultants:

Brown Boveri Canada, Inc.

Garrett Corporation

General Electric Company

General Railway Signal Company

Union Switch & Signal Division, American Standard, Inc.

Westinghouse Electric Corporation

Comstock Engineering, Inc.

Ohio Brass, Inc.

Siemens-Allis, Inc.

Frasco & Associates, Inc.

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EXECUTIVE SUMMARY

Electromagnetic interference, generated by rail transit propulsion equipment, can cause a transit system's signaling system to malfunction, resulting in potential reliability and safety problems. These problems have been complicated and increased by the introduction and growing use of new types of solid state propulsion control.

Two types of electromagnetic interference -- inductive and conductive -- have been found to be the major sources of electromagnetic incompatibility between propulsion and signaling subsystems in rail transit operations. The mechanism of conductive interference is described in Part 1 of this volume, as are audio-frequency track circuits and solid-state propulsion control.

In response to the electromagnetic interference and compatibility problem, the Urban Mass Transportation Administration (UMTA), the transit supply industry and its consultants, and the transit operators themselves have developed, tested, applied, and refined a number of suggested test procedures to ensure compatibility between propulsion and signaling equipment in U.S. transit systems.

Note that these are only suggested test procedures designed to acquire valid data. In-depth knowledge of instrumentation procedures and techniques is required to assemble and operate the equipment configurations described herein. The analysis, evaluation and interpretation of data collected will require detailed knowledge of the systems being examined as well as of various data reduction techniques. It is recommended that only experienced personnel conduct these tests and that all safety precautions be observed during test conduct.

These procedures are tested methods for determining the susceptibility of signaling systems to electromagnetic interference, and for measuring the electromagnetic emissions of electrical power subsystems in the field, in the laboratory, and in track circuits.

Appendices to this report include definitions of terms and systems of units, and sample outputs of tests using the suggested test procedures.

PART 1.
INTRODUCTION TO CONDUCTIVE INTERFERENCE MECHANISMS IN RAIL TRANSIT SYSTEMS USING SOLID-STATE PROPULSION CONTROL

1. INTRODUCTION

This presentation is a brief review of the mechanisms that produce conductive interference in the track circuits of rail transit systems employing solid-state propulsion control. A more detailed account is presented in another report. (Ref. 1-1.)

2. TRACK CIRCUITS

2.1 Audio-Frequency Track Circuits

Figure 1-1 shows a typical jointless audio-frequency track circuit of the type employed at MARTA, WMATA, and portions of the MBTA, CTA, and Cleveland, as well as the new Baltimore and Miami systems. In this type of system, rate-coded bursts of audio-frequency current are injected by means of resonant impedance bonds at the transmitting ends of track blocks, and are received at the receiving ends of the blocks. A number of audio carrier frequencies are used cyclically down the track. Figure 1-2 shows typical track circuitry in detail.

2.2 Power-Frequency Track Circuits

Power frequency track circuits, which are used on some older systems, operate at frequencies from 25 to 300 Hz. Figure 1-3 shows one track circuit in a power-frequency signaling system. Power-frequency track circuits operate similarly to audio frequency circuits in that the track circuit signal path is completed through the transmitter, running rails and the receiver relay. The major difference is that power frequency circuits employ insulated joints instead of impedance bonds to electrically isolate and define adjacent blocks so that only the current associated with a block signal circuit flows in that signal block. Block occupancy by a train's wheel-axle assembly shunts the signal path, de-energizing the relay and activating a block occupied signal. When a block is unoccupied the relay is energized and a block unoccupied signal is activated. Reference 1-2 provides detailed information on the operation of power-frequency track circuits.

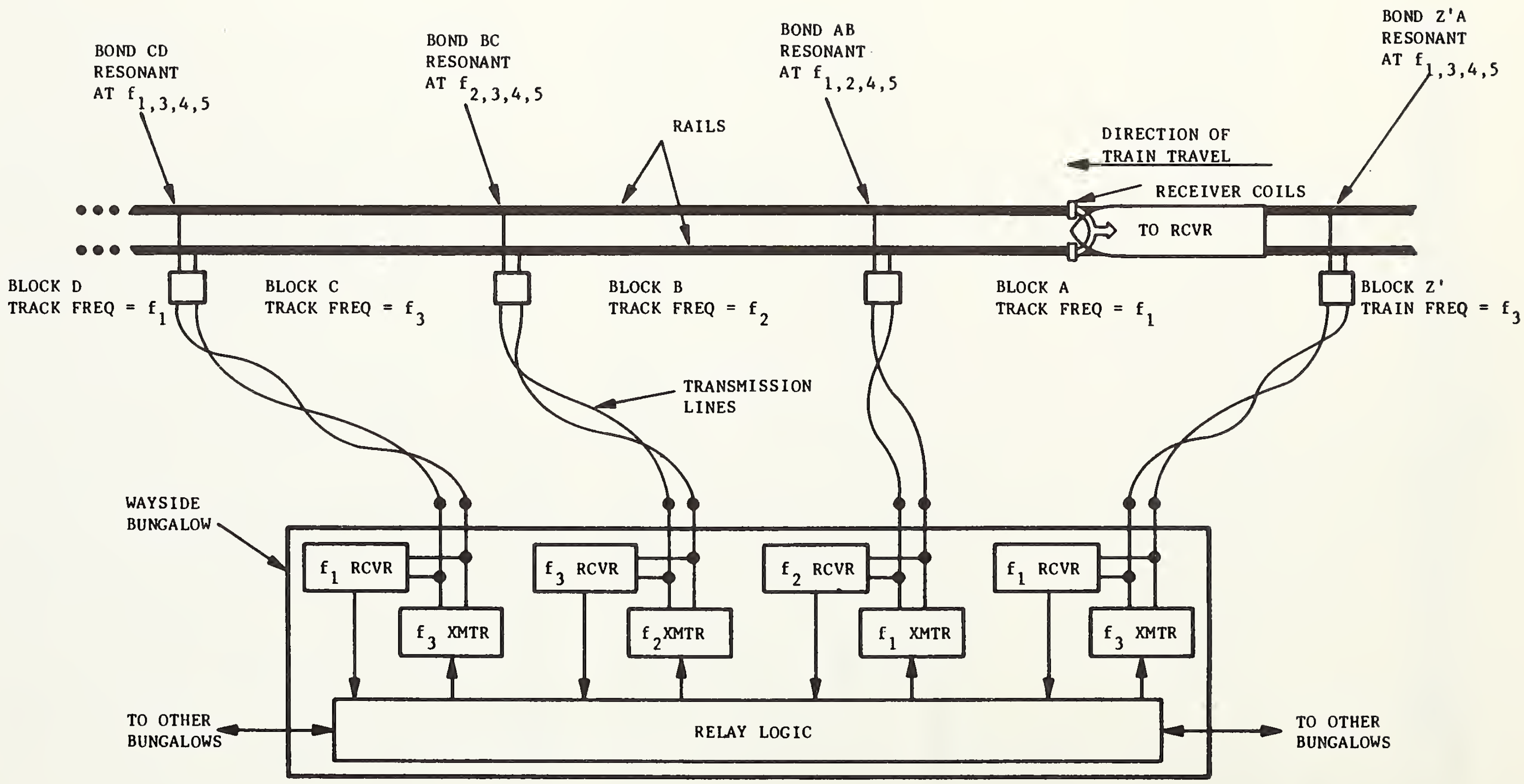

FIGURE 1-1. JOINTLESS AUDIO-FREQUENCY TRACK CIRCUIT

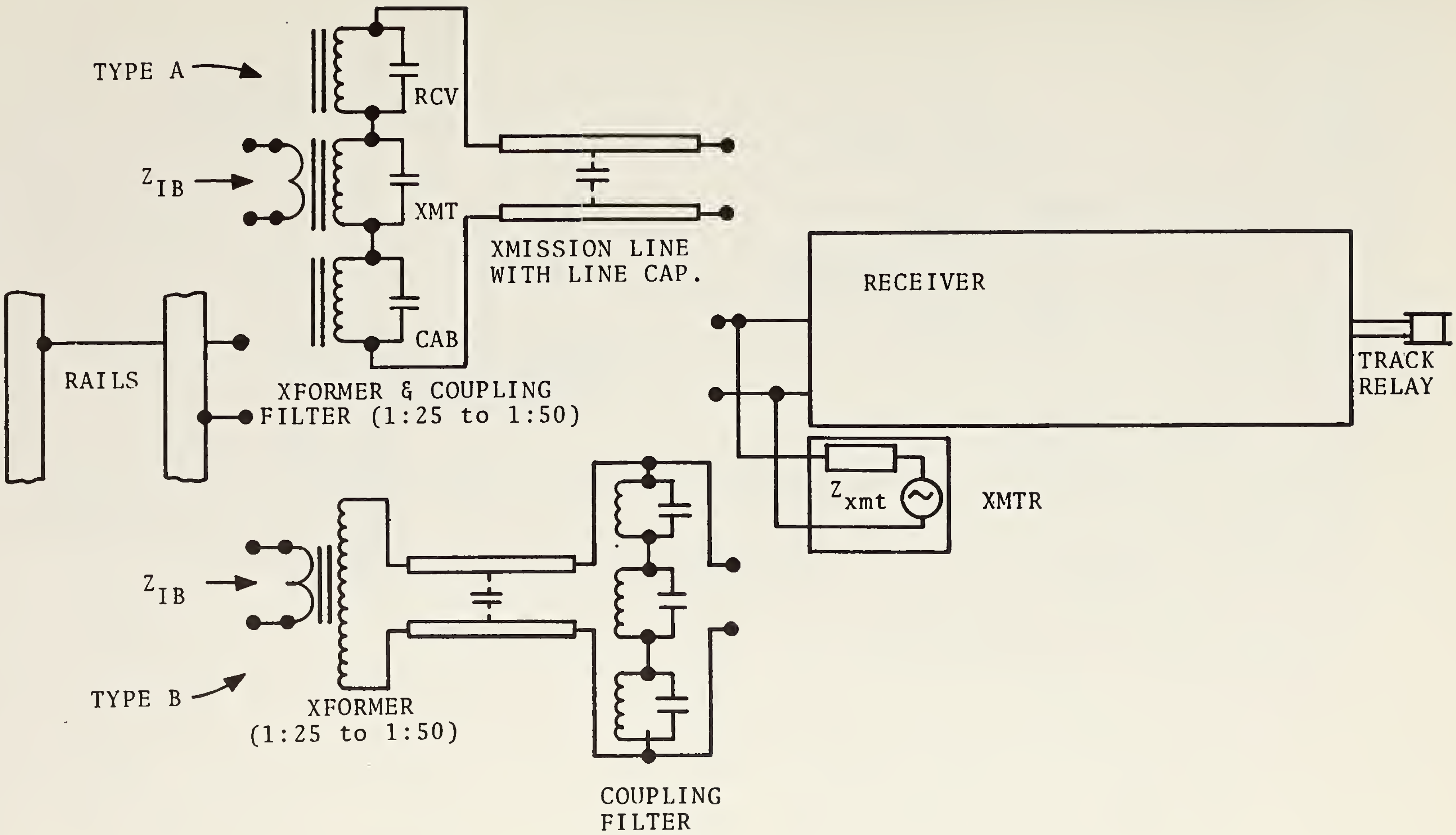

FIGURE 1-2. AUDIO-FREQUENCY TRACK CIRCUITRY

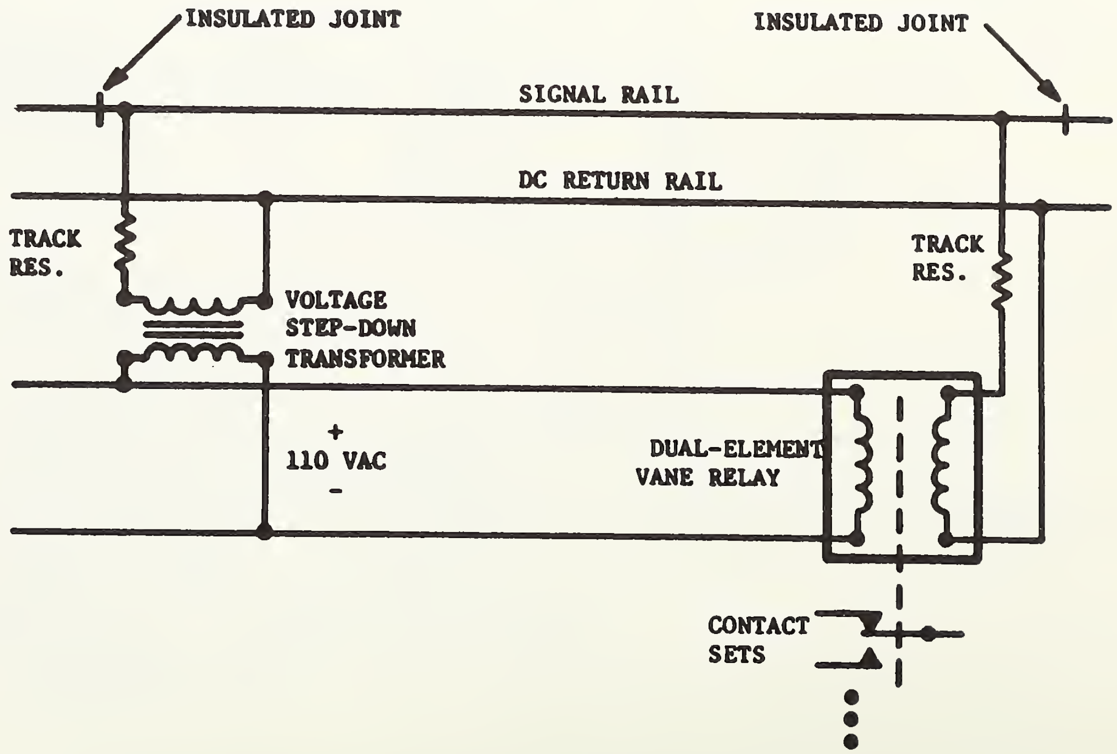

FIGURE 1-3. A SINGLE-RAIL POWER-FREQUENCY TRACK CIRCUIT

3. SOLID-STATE PROPULSION CONTROL

3.1 Description

Two types of solid-state propulsion control currently are in use in rapid transit systems. These are dc chopper propulsion control, and ac inverter propulsion control. In both types of solid-state control, high-power solid-state circuits are used to control the flow of electrical power to traction motors, in place of control circuits employing rheostats or switched resistors.

DC chopper propulsion control systems are used to control the flow of dc electrical power from the third rail or overhead catenary to dc traction motors. AC inverter propulsion control systems are used to control the flow of dc electrical power from the third rail or catenary, and to transform the electrical power into polyphase ac power for delivery to polyphase ac motors used for traction. Three-phase ac induction motors are the current standard for ac propulsion.

Of the two types of solid-state control, dc control was developed first, and its use today is more widespread. A growing number of transit systems currently use ac propulsion, and development of ac propulsion control techniques is still continuing. Descriptions of both types of control circuitry, and their interference characteristics, are given below.

3.2 DC Chopper Propulsion Control

Figure 1-4 shows a typical chopper circuit that might be used for dc propulsion control. In operation, propulsive power is controlled by varying the fraction of time that the main thyristor T_M stays on. T_M is gated on to initiate application of the line voltage to the motor. Some time later, T_C, the commutation thyristor, is gated on to trigger an oscillatory loop current around the T_M, T_C, L_C, C_C loop. At some point during the first cycle of this oscillatory loop current, the algebraic sum of motor current and oscillatory loop current through T_M will go to zero, allowing T_M to turn off. Repetition frequency for gating T_M on is typically in the 200-400 Hz range, and the oscillatory frequency provided by L_C and C_C is typically ten times as high.

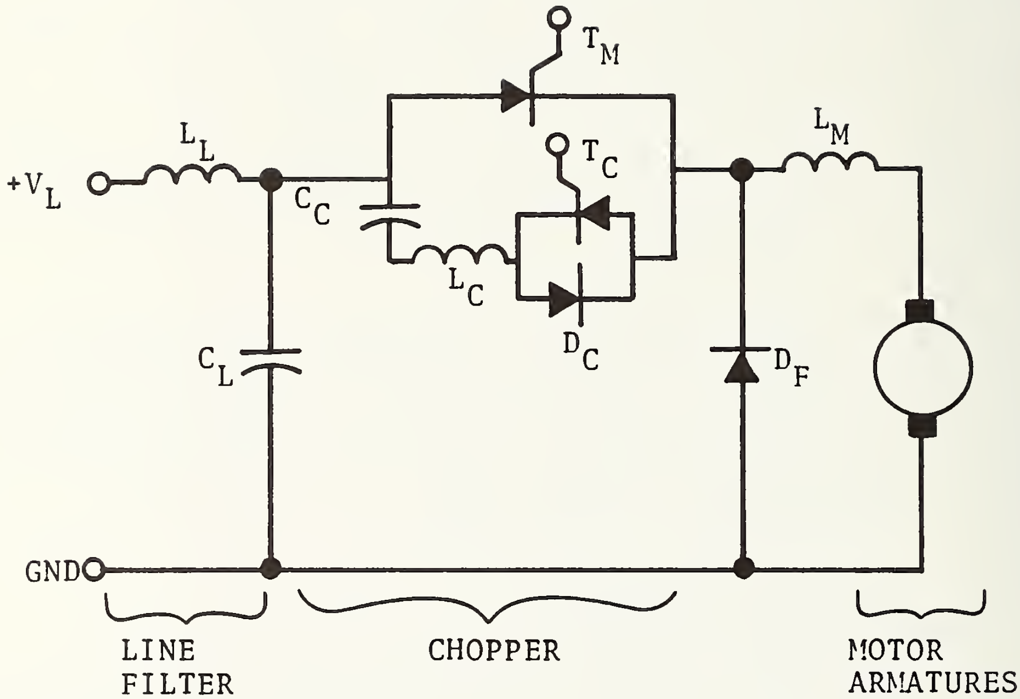

FIGURE 1-4. TYPICAL CHOPPER PROPULSION CONTROLLER

3.3 AC Inverter Propulsion Control

One type of ac propulsion system, developed by Oy Strömberg AB of Finland, and under further development for the U.S. market by the Garrett Corporation, is discussed here. As shown in Figure 1-5, this type of system employs a dc chopper much like that shown in Figure 1-4 to step dc voltage from the third rail up or down for supply to the inverter. The inverter consists of a bank of additional thyristor switch circuits that provide pulsating current at variable frequency to the three phases of the traction motors. Each phase of the inverter employs a thyristor switch to provide positive current and another one to provide negative current. As in the dc chopper circuit shown in Figure 1-3, for every thyristor that conducts power, there is a commutation circuit consisting of an LC circuit and another thyristor, to turn off the power thyristor.

Other ac propulsion systems dispense with the dc chopper and use inverter circuits by themselves. In these systems, pulse width modulation of current pulses to the three phases is used to control power.

3.4 Gate-Turnoff Thyristors

Semiconductor manufacturers have developed a type of thyristor, called the gate-turnoff (GTO) thyristor, that can be turned off by application of an electrical pulse to the thyristor's control gate. GTO power thyristors obviate the need for commutation circuits. Their use in both dc choppers and ac inverters is under development. As is seen in the discussion below, elimination of commutation circuit inductors will ease the job of assuring electromagnetic compatibility between rapid transit propulsion and signaling systems.

3.5 Interference Generation

Two possible modes of audio-frequency interference immediately are evident. The first, called the inductive mode (Refs. 1-3, 1-4, 1-5), can arise because of high levels of stray magnetic flux rich in audio-frequency transients emanating from the inductive circuit components. The second, called the conductive mode, can arise due to harmonics of the audio-frequency transient current waveforms present in propulsion control circuits getting past the line filter (L_L, C_L).

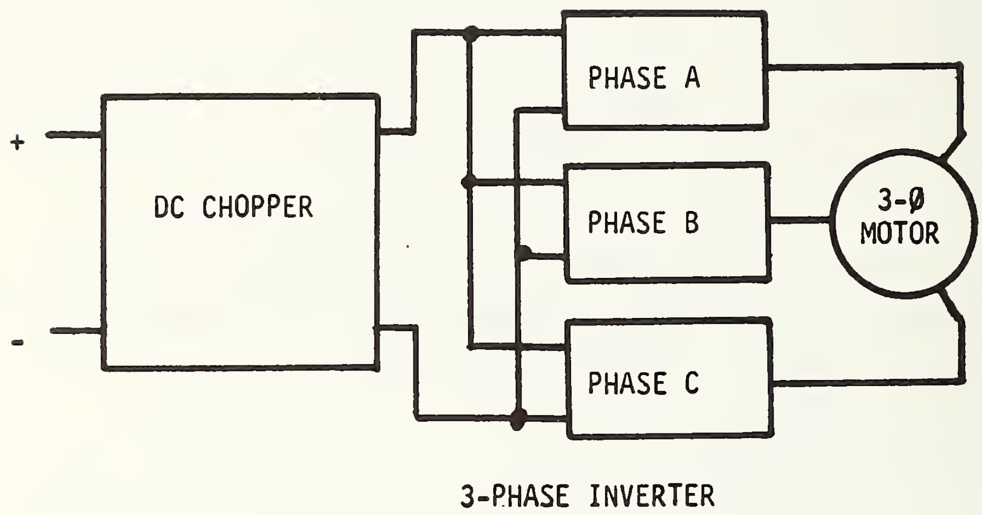

FIGURE 1-5. THREE-PHASE AC INVERTER PROPULSION SYSTEM

In both of these modes, interfering signals can be produced at harmonics of the fundamental chopper frequency, throughout the portion of the audio spectrum used for signaling.

4. CONDUCTIVE INTERFERENCE

A depiction of conductive interference to the signaling system, induced by the propulsive power system, is presented in Figure 1-6. Harmonics produced by the substation rectification system, as well as those produced by dc chopper propulsion controllers on rapid transit cars, can have measurable current content in the audio-frequency signaling range; ac inverters on board ac-drive cars can produce harmonics in the power-frequency signaling range.

AC currents produced by these sources flow in the third rail or catenary, and in the running rails. If double-rail track circuits are used and dc power feed is by overhead catenary, the physical symmetry of the circuit prevents generation of rail-to-rail voltage due to conductive interference current. However, if a third rail is used for dc power feed or if single-rail track circuits are employed, rail-to-rail voltages induced by conductive interference current can occur.

Figure 1-6 pictures a system employing a third rail and jointless audio-frequency track circuits. The third-rail current gives rise to magnetic flux that passes through the loop formed by the running rails, thus inducing circulating current in the loops formed by the running rails and impedance bonds. The ratio of circulating current to third-rail current is equal to the ratio of mutual inductance between the third rail and running-rail loop to the self-inductance of the running rail loop. The value of this ratio is approximately 0.17 for typical third-rail geometries. When operating over the jointless track with audio-frequency ATC, the pickup coils on cars will be subjected to 17 percent of the conductive interference current flowing in the third rail.

When the third rail passes by two complete track circuits without changing sides, the loop currents of the two track circuit loops are equal and flow in the same circular direction. In this case, the contributions of loop current flowing through an impedance bond from the two track circuits on either side exactly cancel, resulting in zero conductive interference current through the bond. However, if the third rail changes sides at or near a bond location, the

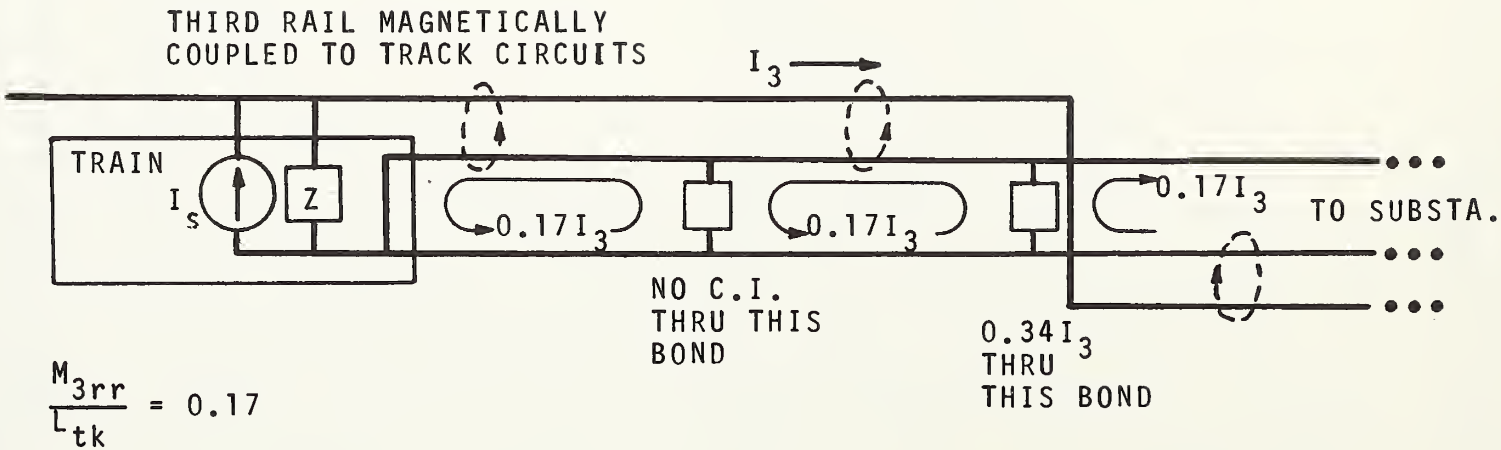

FIGURE 1-6. THE CONDUCTIVE INTERFERENCE MODEL

loop currents flow in opposite circular direction and in the same direction through the intervening bond, producing conductive interference current through the bond of 2 x 17 = 34 percent of the conductive interference current in the third rail.

Formulations similar to those above exist for modeling conductive interferenc in single-rail track circuits or ones using insulated joints. Whatever the symmetry, additional conductive interference can arise from unequal wheel-rail contact resistances, unequal bond-lead impedances at cross-bonding locations, and any assymetry in the layout of conducting paths for dc propulsion current.

Conductive interference is evidenced by interfering signals present at bond locations ahead of or behind the train but not at locations underneath the train where inductive interference has been found to predominate. Conductive interference potentially can cause two types of false responses: false pickup of a dropped track relay; or false dropping of a picked-up track relay. False pickup can cause a potential safety problem.

Recent investigation of chopper-induced conductive interference levels for multi-car trains has led to the realization that these levels are of a statistical nature. Figure 1-7 depicts the phasor addition of contributions from separate cars of a multi-car train at a particular harmonic frequency. While it is possible for the contributions to add nearly in phase, that will happen only rarely. A statistical distribution of overall harmonic amplitude results, with the rms value of current increasing as $N^{1/2}$, and the maximum current increasing as N, where N is the number of cars in a train.

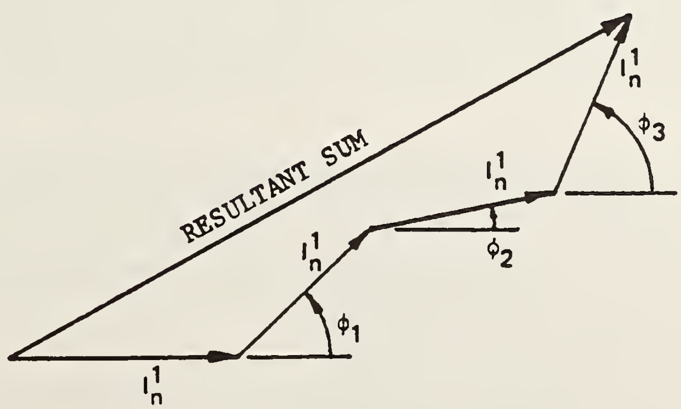

FIGURE 1-7. ADDITION OF SEPARATE n^{th}-HARMONIC COMPONENTS FOR A MULTICAR TRAIN

5. CONCLUSIONS

At this time, conductive interference mechanisms are well understood. In addition to the extensive observations that have been made in the field under actual operating conditions, procedures now exist for observing interference levels in the laboratory for choppers and track circuits that are still in the engineering stage of development. Use of these procedures has proven beneficial in assuring compatibility of propulsion and signaling equipment for rapid transit systems currently under development.

6. REFERENCES

1-1 Holmstrom, F. Ross, "Conductive Interference in Rapid Transit Signaling Systems - Volume I: Theory and Data," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington DC, November 1985, UMTA-MA-06-0153-85-5.

1-2 West, Michael D., & F. Ross Holmstrom, "Laboratory and Field Testing of NYCTA Power Frequency Track Circuits," U.S. Department of Transporation, Urban Mass Transportation Administration, Washington DC, February 1986, UMTA-MA-06-0153-85-12.

1-3 Holmstrom, F. Ross, "Inductive Interference in Rapid Transit Signaling Systems - Volume I: Theory and Background," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington DC, May 1986, UMTA-MA-06-0153-85-7.

1-4 "Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington DC, March 1987, UMTA-MA-06-0153-85-8.

1-5 Holmstrom, F. Ross, "Inductive Interference in Rapid Transit Signaling Systems - Volume III: Data and Test Results," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington DC, January 1986, UMTA-MA-06-0153-85-9.

PART 2
REPORT FORMATS, RECORDING AND
DOCUMENTATION PROCEDURES

1. SCOPE

This section documents the formats and procedures used in formulating and applying these suggested test procedures.

2. FORMAT

The test method format shall be as specified in Table 2-1.

TABLE 2-1. TEST METHOD FORMAT

Title Format: <u>TEST METHOD NO.</u> <u>DESCRIPTION/TITLE</u> <u>FREQUENCY RANGE</u>

Sections:

1. PURPOSE
2. APPLICATION
3. TEST MEASUREMENT APPARATUS
4. TEST PROCEDURE
5. TABULATION OF RESULTS
6. NOTES

<u>Test Method Numbering System</u>

The test method numbering system shall be of the form RT/XXYYZ. The prefix RT denotes RAIL TRANSIT. Letters XX denote abbreviations for test method classifications as listed in Table 2-2 below. Numbers YY (01 to 99) indicate the number of a test of a particular classification. Suffix letter Z is a letter issued sequentially (i.e., A, B, C, ...) to denote a test of a specific number and classification, that has been adapted to an application involving specific equipment or requirements.

TABLE 2-2. TEST METHOD CLASSIFICATION

METHOD XX	DESCRIPTION
IS	Inductive Susceptibility
IE	Inductive Emissions
CS	Conductive Susceptibility
CE	Conductive Emissions
OC	Operating Characteristics

3. TEST REPORTING REQUIREMENTS

Integral to the performance of each test method is the documentation of testing scenarios and test results. Table 2-3 contains a sample test report format outlining report requirements.

TABLE 2-3. TEST REPORT REQUIREMENTS

1. Photo or Diagram of Test Configuration
2. Test Scenario

   Significant Details Concerning the specific Tests to be conducted and Test Methods applied.

3. Measurement Equipment

   a. Description, including manufacturer, model name and number, operating voltage and current, and frequency and voltage ranges used.

   b. Serial number

   c. Last Calibration Date

   d. Transfer Characteristics and Calibration Factors for Measurement Sensors (i.e., probes, loops, antennas, etc.)

4. Measured Levels of Emission and/or Susceptibility for each Required Test Parameter and Condition
5. Graphs of Measured Data
6. Susceptibility Criteria

   a. Circuits, Outputs, Displays to be monitored

   b. Criteria for normal and degraded performance, and malfunction.

PART 3
CONDUCTIVE SUGGESTED TEST PROCEDURES

METHOD RT/CS01A
CONDUCTIVE SUSCEPTIBILITY OF AUDIO-FREQUENCY RATE-CODED SIGNALING SYSTEMS FROM 300 Hz TO 10 KHz

1. PURPOSE

The purpose of this test is to determine the susceptibility of audio-frequency rate-coded track circuit receivers to types of interference caused by conductive emissions.

2. APPLICATION

This method is applicable to all audio-frequency track circuit equipment operating at frequencies between 300 Hz and 10 kHz in which the operating signal waveform consists of amplitude modulated audio-frequency tones modulated at a selectable discrete rate (i.e., code rate).

3. APPARATUS

The test apparatus shall consist of the following:

a. Amplitude-modulated audio-frequency signal generator Wavetek Model 146 or equal

b. High-power audio frequency amplifier with low impedance output

c. Oscilloscope

d. RMS voltmeter

4. TEST PROCEDURE

4.1 Operating Conditions

To evaluate the effects of conductive interference, two distinct operating conditions must be considered:

Case I - track circuit occupied by vehicle

Case II - track circuit unoccupied

Only test procedures for Case II are presented here. The test procedures of Method RT/IS01A (Inductive Susceptibility), where the track circuit transmitter rail output has been disabled, are directly applicable to Case I conductive susceptibility.

Therefore, in the susceptibility tests which follow, the track circuit transmitter track output remains connected and operational with the simulated or pre-recorded conductive interference source attached in parallel. Note that the susceptibility criterion is evidenced by an indication that the track circuit appears to be occupied, i.e., the track relay drops.

4.2 Verification of Nominal Track Circuit Operation

Verify that the track circuit receiver is working according to the manufacturer's specifications, with the transmitter and receiver properly loaded, and with the transmitter track signal and reference signals supplied to the receiver as required. Then, set up the equipment as shown in Figure RT/CS01A-1. Adjust the receiver threshold so that it is at least sensitive position (minimum gain). Complete the test procedure and then repeat it with the receiver threshold at its most sensitive setting (maximum gain).

4.3 Continuous Wave (CW) Test

Turn on the track circuit transmitter to emit a valid carrier and code rate. Adjust the carrier frequency of the audio-frequency signal generator to the specified operating frequency of the receiver of the track circuit under test. Adjust the modulation index to 100 percent. Adjust the modulation frequency to 0 Hz (CW operation) and slowly increase the applied voltage until the track circuit indicates an occupied condition (i.e., track relay drops). Record this value, which is the CW Interference Susceptibility Level, Vrms, at center frequency. Adjust the carrier frequency of the signal generator in 10 Hz increments above and below the specified operating frequency. For each increment, slowly vary the applied voltage to establish the threshold for dropping the relay; record the frequency and level for each increment. Continue incrementing the carrier frequency until the threshold is in excess of 0.5 Vrms. Repeat this test for all valid track circuit transmitter carrier and code rate frequencies which can be present in an unoccupied track circuit.

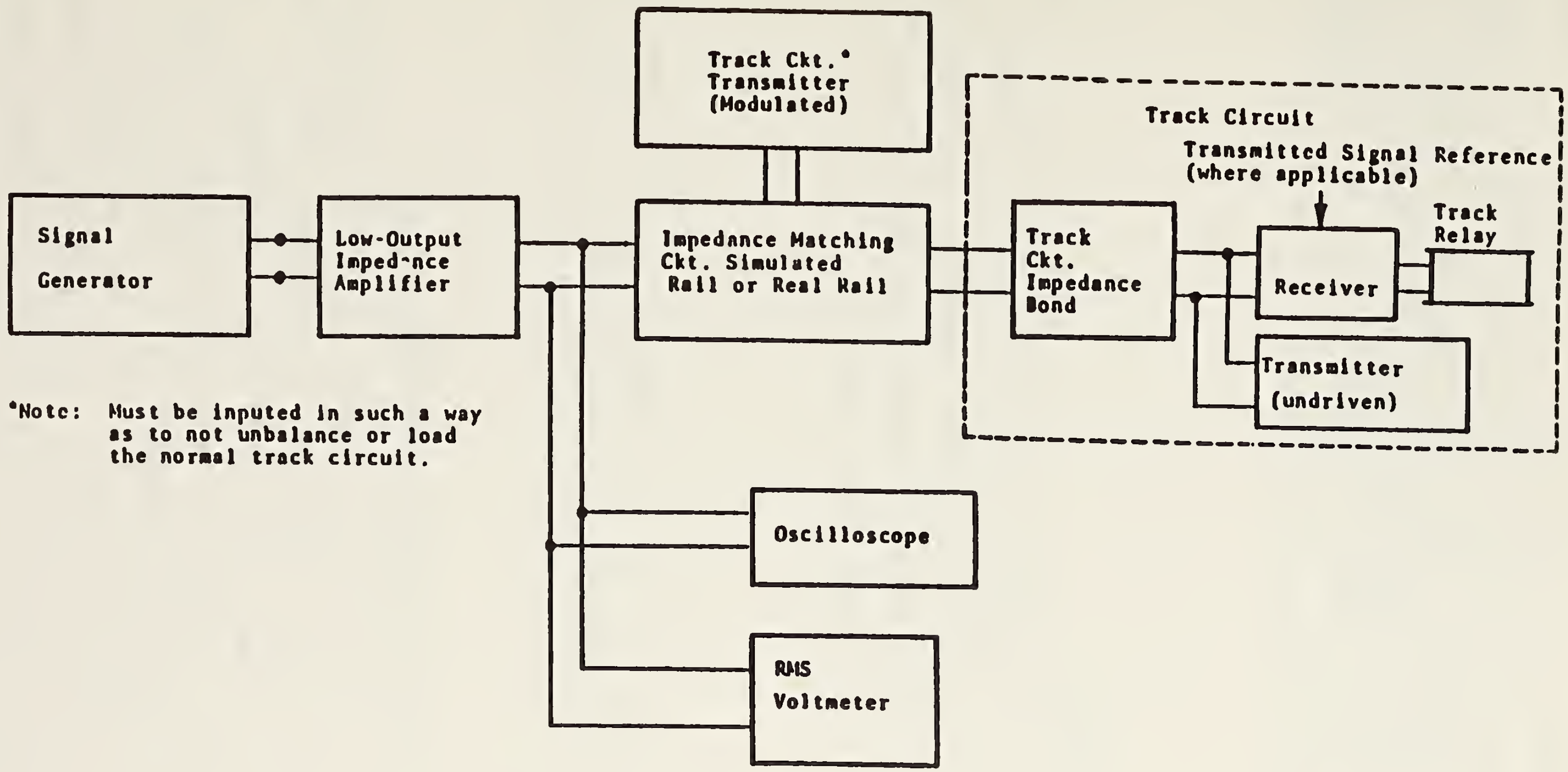

FIGURE RT/CS01A-1. ARRANGEMENT OF TEST APPARATUS FOR PERFORMING MEASUREMENT OF CONDUCTIVE SUSCEPTIBILITY OF RATE-CODED AUDIO-FREQUENCY SIGNALING SYSTEMS

5. TABULATION OF RESULTS

Record the susceptibility results on a data sheet. Where actual recorded signals are used (see note 6.3), the results should be presented in narrative form including the source of the recorded signal, the tape identification and its storage location, the test method followed in producing the tape, the scale factor, and the resultant effect that the signal had on the track circuit.

6. NOTES

6.1 Erratic CW Test Behavior

Note that some erratic receiver behavior may occur in the CW test of section 4.2 when the CW interference frequency is near the signaling frequency. This is normal due to extra modulation components caused by the beat between the interference and normal track signals. Increase the interference level slowly. The threshold (lowest level signal which causes the relay to drop away) should be recorded.

6.2 Applicability

The intereference susceptibility as measured in this test method is representative of the magnitude and characteristics of the differential (circulating) current in the running rails to which the track circuit receiver is susceptible.

6.3 Use of Actual Recorded Conductive Interference Signals

Recommended Practices RT/CE01A and RT/CE02A describe techniques for tape recording actually occurring conductive interference signals arising from vehicular propulsion systems and rectification substations. Such tape recordings can be used in place of the signal generator pictured in Figure RT/CS01A-1 to assess conductive susceptibility of track circuits to actually occurring potentially interfering signals. To do so, the playback tape recorder is substituted for the signal generator. A current sensor is included in the circuit between impedance matching circuit and track circuit impedance bond. Current sensor output is fed to an FFT analyzer. The recorded reference signal level (described in RT/CE01A and RT/CE02A) is observed on the FFT analyzer, and

the amplifier is adjusted to produce the desired level of overall record-playback gain. Operation of the track circuit in the presence of played-back interference signal is then observed. Note that drawing accurate inferences from this procedure requires thorough knowledge of the impedance and coupling characteristics of circuits comprised of third rail, running rails, and impedance bonds.

METHOD RT/CE01A
CONDUCTIVE EMISSION TEST, SUBSTATION

1. PURPOSE

The purpose of this test is to measure the conductive interference current flowing in the propulsion supply feeder.

2. APPLICATION

The test is applicable to propulsion systems using dc input power. The test measures the conductive emissions produced by the vehicle(s) together with those caused by the substation. Under some conditions, it may be difficult or impossible to separate these two effects. This test method has been applied successfully and an example of the results is presented in Appendix B.

3. TEST FACILITY AND APPARATUS

3.1 Test Facility

The test facility shall consist of a section of dry test track fed at one end by a power substation. The portion of track required for train acceleration should be without power gaps, to avoid transients which can obscure the data. It shall be possible to isolate the test section from all other power substations and from all other loads which can produce audio-frequency signals.

The measurement resulting from this test method reflects the characteristics and loading of the specific substation as well as the characteristics of the vehicle used. It is important that the tests be conducted as close as possible to a substation to:

(1) Minimize the possibility of spurious results due to frequency-dependent impedance characteristics of the rail loop

(2) Minimize error due to the finite source impedance of the car.

The test results also reflect the effects of vehicle auxiliaries, depending in detail on the exact equipment configuration in effect.

3.2 Apparatus

The following equipment is required:

a. Suitable current sensor and associated signal conditioning equipment (see RT/CE01A Exhibit A).

b. FFT real time spectrum analyzer, GEN RAD Model 2512 or similar.

c. X-Y plotter compatible with the spectrum analyzer.

d. Instrumentation tape recorder, Brüel and Kjær Model 7005 with Direct Record unit ZE-0299, or equivalent (IRIG Intermediate Band, Direct Record, 15, in/sec with at least two channels). (See Note 6.1.)

e. Four-pole Butterworth Filter, Krohn-Hite type 3343R or equivalent.

f. Strip-chart recorder and adjunct instrumentation, as required to record essential vehicle operating parameters. (See paragraph 4.1.)

g. Means to assure proper calibration of the installed arrangement of current sensor, preamplifier, and amplifier.

h. Communication equipment to coordinate train operation with the substation test crew.

4. TEST PROCEDURE

4.1 Vehicle Configuration

The test train consist(s) shall be as specified by the Authority and shall include a maximum-length train. The tests shall be conducted at empty vehicle weight (AWO)[1] and for the acceleration mode only. If required, the data can be adjusted for other weights and other operating modes, such as dynamic or regenerative braking, in accordance with known characteristics of the propulsion equipment. The tests shall be conducted with the objective of obtaining worst-case data.

---

[1]AWO - Actual Weight Zero Loading.

4.2 Vehicle Instrumentation

Appropriate instrumentation and a strip-chart recorder shall be installed in one of the test vehicles to record the following information during each test:

a. DC line voltage or input filter capacitor-bank dc voltage

b. Propulsion system dc input current

c. Vehicle speed

d. Armature current on one traction motor

e. DC-link voltage and current if ac drive propulsion is used

f. Field current

g. P-Signal (or other train command signal)

4.3 Substation Instrumentation

To assess stray pickup the current sensor initially shall be installed immediately adjacent to the positive bus of the power substation.

A preliminary run as described in Paragraph 4.4 then shall be made with all instrumentation active, and with the current sensor still adjacent to the positive bus, to assess stray pickup. If stray pickup is believed to be excessive, cabling and equipment placement shall be altered to reduce stray levels.

With the output terminals of the current sensor shorted, a maximum-length train shall be accelerated to verify satisfactory noise immunity of the instrumentation exclusive of the current sensor.

A calibration sweep covering the frequency range of interest shall be performed. Using a fixed signal amplitude in the range of expected signal levels, the frequency sweep should be recorded on tape for use in later data reduction and analysis. Additionally, the sweep should be captured on the spectrum analyzer, plotted and fully annotated. This provides characterization of instrumentation throughput for the entire measurement configuration.

For purposes of assuring proper operation of the instrumentation, a calculation shall be made of the expected amplitude of the spectral display due to the calibration signal. Agreement should be within ± 1 dB. All harmonic amplitudes shall be referenced to these levels.

Some spectrum analyzers do not automatically correct for the amplitude reduction associated with use of Hann windowing. In such an event, the data, as recorded with the spectrum analyzer, shall be adjusted by +1.8 dB, to obtain actual levels. This correction must be made to correctly correlate the actual level of the injected reference signal with its amplitude as measured by the spectrum analyzer.

Note: Optionally, the current sensor can be located on the negative return from the track on which the train is to be tested. Caution should be exercised to insure that all of the traction return current in fact does flow through the return cable being monitored.

4.4 Emission Test

The current sensor shall be installed in the positive bus. The test train shall be placed with its trailing end at the dc return to the substation, and then accelerated under maximum power away from the power substation. The spectrum analyzer, in peak-hold mode and in Hann windowing configuration, shall acquire data throughout the acceleration cycle. To avoid obscuring the data by transients, spectrum analyzer data acquistion shall be delayed until after all train contactor closures related to initial power application have taken place. To assess the effects of initial chopper sweeping or pulse-skipping, the spectrum analyzer data shall be captured on two succesive runs: on the first, beginning immediately after contact closure; and on the second, beginning at a train speed above which chopper frequency sweeping or pulse-skipping ceases. The spectrum analyzer data shall be plotted and fully annotated upon completion of each run. The on-board instrumentation also shall acquire data throughout each test run. In addition, the maximum current registered by the substation dc meter shall be recorded. Results shall be checked against the noise immunity runs described in 4.2 to assure that stray pickup does not degrade accuracy more than a tolerable amount. (For example, stray pickup 20 dB below an actually observed harmonic line introduces an uncertainty of ± 1 dB in the amplitude of that line.

5. TABULATION OF RESULTS

The results shall be summarized in tabular form. The table shall contain the following minimum information:

a. Test description (e.g., 2-car train, outbound)

b. Maximum reading of substation ammeter

c. Vehicle data: maximum speed, minimum line voltage, maximum line current, maximum motor current

d. Frequency and level of measured emissions in signaling band.

In addition, the following data shall be presented:

a. All spectral plots made, fully annotated

b. Strip charts of vehicle parameters

c. Test equipment certification information

d. Tape recording of test runs

6. NOTES

6.1 Alternate Tape Recorder Operation

Direct-record tape recording is a band-pass process, with both lower and upper cutoff frequencies. Many tape recorders do not possess a low enough lower cutoff frequency to record signals accurately at the lower power frequencies used in signaling. When interfering signals must be recorded at such frequencies, and direct-record tape recording does not provide adequate low-frequency response, fm recording may be employed.

6.2 Spectral Plots

The spectra plotted in accordance with 4.3 display only the maximum instantaneous magnitude that any harmonic has reached during the test. Additional information may be obtained by later analysis of the tape recorded data. Analysis such as the application of frequency expansion techniques may be helpful in discriminating between propulsion and power supply harmonics.

6.3 Vehicle Auxiliaries

The test results also reflect the effects of vehicle auxiliaries, depending in detail on the exact equipment configuration in effect.

EXHIBIT A: SUGGESTED INSTRUMENTATION

The measurement of conductive emissions is difficult due to the rich spectra, wide signal range, and high-noise environment. The setup presented herein has been applied successfully.

CURRENT SENSORS

The suggested current sensor is an LEM type LA 10000-S Transfoshunt.[1] The Transfoshunt (see Figure RT/CE01A-A-1) consists of: 1) a gapped iron core with primary and secondary windings; 2) a Hall sensor, which is placed in the gap; and 3) a servo amplifier to drive the secondary winding.

The current to be measured is applied to the primary, which consists of conductors passed through a window, as is done with conventional current transformers. The magneto-motive force (MMF) generated by the primary current produces a flux in the air gap. The flux is sensed by the Hall sensor; the voltage generated by the sensor is applied to the amplifier; and the amplifier drives the secondary winding via a measuring resistor so as to null the air gap flux. Consequently, the voltage developed across the measuring resistor replicates the primary current, differing from it only by the small errors inherent in the Hall sensor and the amplifier, further reduced by the desensitivity factor of the closed-loop system, and by the ability of the amplifier to drive the secondary at the required rates. The measured frequency response was flat from dc to 7 kHz, rising +6 dB at 10 kHz.

Other essential characteristics are:

- Measuring range - 10,000 ampere-turns
- Output sensitivity - 500 μV/ampere
- Window area - 208 sq cm.

[1] Mfg. by Liaisons Electroniques Mechaniques S.A., 14 F route de Saint-Julier, CH-1227 Carouge/Geneve, Switzerland. A sensor with compensation optimized for maximally flat frequency response should be specified.

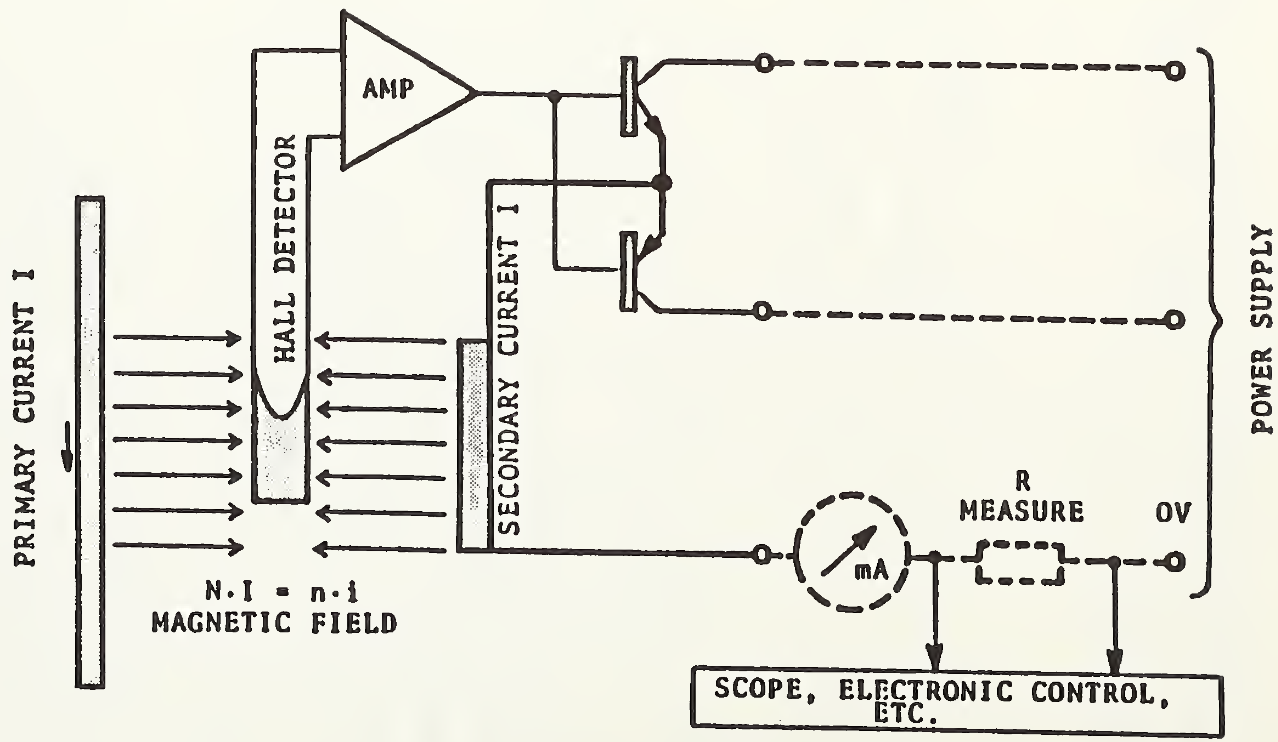

FIGURE RT/CE01A-A-1. LEM TRANSFOSHUNT

An elementary schematic of the complete instrumentation is shown in Figure RT/CE01A-A-2. The Transfoshunt is placed in a substation circuit breaker enclosure, with the preamplifier-line driver nearby. A 4-pole Butterworth filter is used to split the signal into two frequency ranges in order not to exceed the dynamic range capability of the tape deck and, on occasion, of the spectrum analyzer. In the latter event, each test is performed twice: once without the filter, and once with the filter at the spectrum analyzer input. The audio oscillator is used for spot calibration and checkout of the equipment.

NOTE: The harmonic distortion produced by the test equipment has not been fully characterized. Such distortion can lead to the perception of higher emissions than actually produced. However, the harmonic distortion of the test equipment has been determined to be sufficiently low to permit specification compliance testing to a specified emission level of 50 mA.

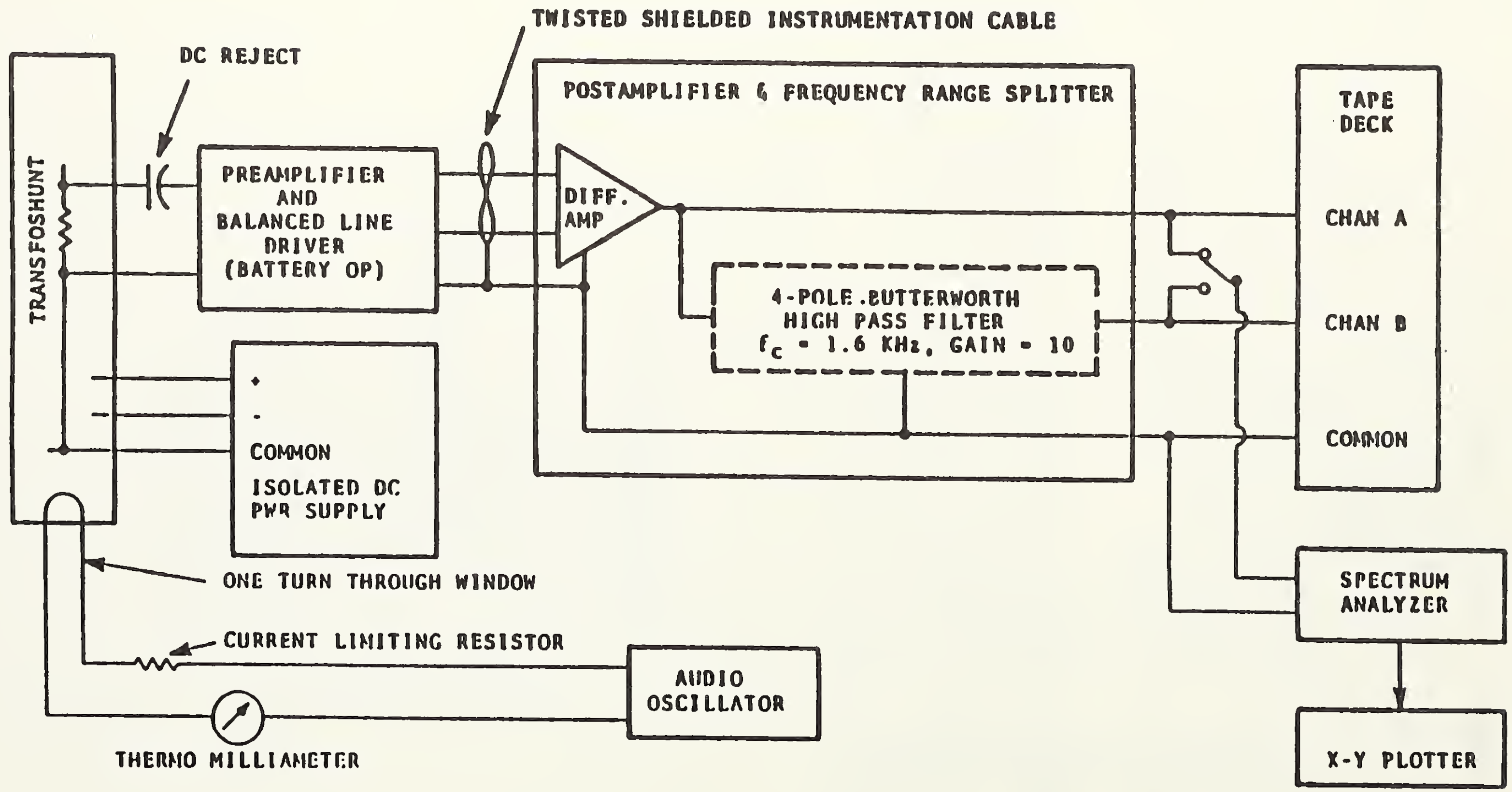

FIGURE RT/CE01A-A-2. ELEMENTARY INSTRUMENTATION SCHEMATIC FOR CONDUCTIVE EMISSION TEST

METHOD RT/CE02A
CONDUCTIVE EMISSION TEST, VEHICLE

1. PURPOSE

The purpose of this test is to measure, on board, the conductive emissions of a single transit vehicle.

2. APPLICATION

This test is applicable to propulsion systems using dc input power. The test measures the conductive emissions produced by vehicle(s) together with those caused by the substation. Under some conditions it may be difficult or impossible to separate these two effects. The test procedure has been applied successfully, and example of the results is presented in Appendix B. The procedure has also been applied in the laboratory, with the propulsion equipment driving a simulated load.

3. TEST FACILITY AND APPARATUS

3.1 Test Facility

The test facility shall consist of a section of dry test track fed at one end by a power substation. The portion of track required for train acceleration should be without power gaps, to avoid transients which can obscure the data. The test section shall be isolated from all other power substations or the test should be conducted when or where no other traffic can contribute signal components.

The measurement resulting from this test method reflects the characteristics and loading of the specific substation as well as the characteristics of the vehicle used. It is important that the tests be conducted as closely as possible to a substation to:

(1) Minimize the possibility of spurious results due to frequency-dependent impedance characteristics of the rail loop

(2) Minimize error due to the finite source impedance of the car

3.2 Apparatus

The apparatus required for this test is as follows:

a. Suitable current sensor and associated signal conditioning equipment (See RT/CE02A Exhibit A.)

b. FFT real time spectrum analyzer, GEN RAD Model 2512 or similar.

c. X-Y plotter compatible with the spectrum analyzer.

d. Instrumentation tape recorder, Brüel and Kjær Model 7005 with Direct Record Unit ZE-0299, or equivalent (IRIG Intermediate Band, Direct Record, 15 in/sec, with at least two channels). (See Note 6.1)

e. Four-pole Butterworth Filter, Krohn-Hite type 3343R or equivalent.

f. Strip-chart recorder and adjunct instrumentation, as required to record essential vehicle operating parameters, as stated in Paragraph 4.1.

g. Means to assure proper calibration of the installed arrangement of current sensor, preamplifier, and amplifier.

4. TEST PROCEDURE

The test shall be conducted with a single transit vehicle. If a 2-car consist must be used, the other car shall be off, i.e., with its line switch or circuit breaker open. The tests shall be conducted at empty vehicle weight (AW0) and for acceleration mode only. If required, the data shall be adjusted for other weights and other modes, such as dynamic and regenerative braking, in accordance with known characteristics of the propulsion equipment. The tests shall be conducted with the objective of obtaining worst-case data.

4.1 Vehicle Instrumentation

Appropriate instrumentation and a strip-chart recorder shall be installed on the test vehicle, as shown in Figure RT/CE02A-A1, to record the following information, as required, during the test:

a. DC line voltage or input filter capacitor-bank dc voltage

b. Propulsion system dc input current

c. Vehicle speed

d. Armature current of one traction motor

e. DC-link voltage and current if ac drive

f. Field current

g. P-Signal (or other train command signal)

4.2 Conductive Emission Instrumentation

To assess stray pickup the current sensor and its pre-amplifier first shall be installed immediately adjacent to the conductor in which the current will be sensed, i.e., the positive input line of the propulsion subsystem.[2]

Then, to assess stray pickup, a preliminary run as described in 4.3 shall be made with all instrumentation active, and with the current sensor still adjacent to the dc power line instead of in the line. If stray pickup is believed to be excessive, cabling and equipment placement shall be altered to reduce stray levels. Notice will be taken of spectral content of the harmonic signal to ascertain true harmonic roll-off versus wide-band stray pickup.

With the output terminals of the current sensor shorted, the test train shall be accelerated to verify satisfactory noise immunity of the instrumentation, exclusive of the current sensor.

A calibration sweep covering the frequency range of interest shall be performed. Using a fixed signal amplitude in the range of expected signal levels, the frequency sweep should be recorded on tape for use in later data reduction and analysis. Additionally, the sweep should be captured on the spectrum analyzer, plotted and fully annotated. This provides characterization of instrumentation throughput for the entire measurement configuration.

For purposes of assuring proper operation of the instrumentation, calculation shall be made of the expected amplitude of the spectral display due to the calibration signal. Agreement should be within ± 1 dB. All harmonic amplitudes then shall be determined by reference to this level.

[2]The sensor must be placed in the positive line, to avoid possible conductive and/or capacitive ground loops.

Some spectrum analyzers do not automatically correct for the amplitude reduction associated with use of Hann windowing. In such an event, the data, as recorded with the spectrum analyzer, shall be adjusted by +1.8 dB, to obtain actual levels. This correction must be made to correctly correlate the actual level of the injected reference signal with its amplitude as measured by the spectrum analyzer.

4.3 Emission Test

The current sensor shall be placed in the dc power line. The test train shall be placed with its trailing end at the dc return to the substation and then accelerated under maximum power away from the power substation. The spectrum analyzer, in peak-hold mode and in Hann windowing configuration, shall acquire data throughout the acceleration cycle. To avoid obscuring the data by transients, spectrum analyzer data acquisition shall be delayed until after all train contactor closures related to initial power application have taken place. To assess the effects of initial chopper sweeping or pulse-skipping, spectrum analyzer data shall be recorded on two successive runs: on the first beginning immediately after contact closure; and on the second, beginning at a train speed above which chopper frequency sweeping or pulse-skipping ceases. The spectrum analyzer data shall be plotted and fully annotated upon completion of each run. The data specified in 4.1 also shall be acquired throughout each test run.

Results shall be checked against the noise immunity test runs described in 4.2 to assure that stray pickup does not degrade accuracy more than a tolerable amount. (For example, stray pickup 20 dB below an actually observed harmonic line introduces an uncertainty of ± 1 dB in the amplitude of that line.)

5. TABULATION OF RESULTS

The results shall be summarized in a table containing the following information:

a. Maximum vehicle speed

b. Minimum line voltage

c. Maximum line current

d. Maximum motor current

e. Frequency and level of measured emissions in the signaling band

The following additional data shall be presented:

a. Fully annotated spectral plots

b. Strip charts of vehicle parameters

c. Test equipment certification information

d. Tape recording of test runs

6. NOTES

6.1 Alternate Tape Recorder Operation

Direct-record tape recording is a band-pass process, with both lower and upper cutoff frequencies. Many tape recorders do not possess a low enough lower cutoff frequency to record signals accurately at the lower power frequencies used in signaling. When interfering signals must be recorded at such frequencies, and direct-record tape recording does not provide adequate low-frequency response, fm recording may be employed.

6.2 Spectral Plots

The spectra plotted in accordance with 4.3 display only the maximum instantaneous magnitude that any harmonic has reached during the test. Additional information may be obtained by later analysis of the tape recorded data. Analysis such as the application of frequency expansion techniques may be helpful in discriminating between propulsion and power supply harmonics.

6.3 Auxiliaries

The test results also reflect the effects of vehicle auxiliaries, depending in detail on the exact equipment configuration in effect.

EXHIBIT A: SUGGESTED INSTRUMENTATION

The measurement of conductive emissions is difficult due to the rich spectra, wide signal range, and the high-noise environment. The set-up presented herein has been successfully applied.

CURRENT SENSORS

The current sensor is an LEM type LA 600 Transfoshunt.[3] The Transfoshunt (See Figure RT/CE02A-1) consists of: 1) a gapped iron core with primary and secondary windings; 2) a Hall sensor, which is placed in the gap; and 3) a servo amplifier to drive the secondary winding.

The current to be measured is applied to the primary, which consists of conductors passed through a window, as is done with conventional current transformers. The MMF generated by the primary current produces a flux in the air gap. The flux is sensed by the Hall sensor; the voltage generated by the sensor is applied to the amplifier; and the amplifier drives the secondary of the transformer via a measuring resistor so as to null the air gap flux. Consequently, the voltage developed across the measuring resistor replicates the primary current, differing from it only by the small errors inherent in the Hall sensor and the amplifier, further reduced by the desensitivity factor of the closed-loop system, and by the ability of the amplifier to drive the secondary at the required rates. The measured frequency response of a particular unit tested was essentially flat ($\pm$0.5 dB) to 10 kHz.

Other essential characteristics are:

- Measuring range - 1500 ampere-turns
- Output sensitivity - 2 mV/ampere (10 ohm measuring resistor)

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[3]Mfg. by Liaisons Electronique Mechaniques S.A., 14E route de Saint-Julien, CH-1227 Carough/Geneve, Switzerland. A sensor with compensation optimized for maximally flat frequency a response should be specified.

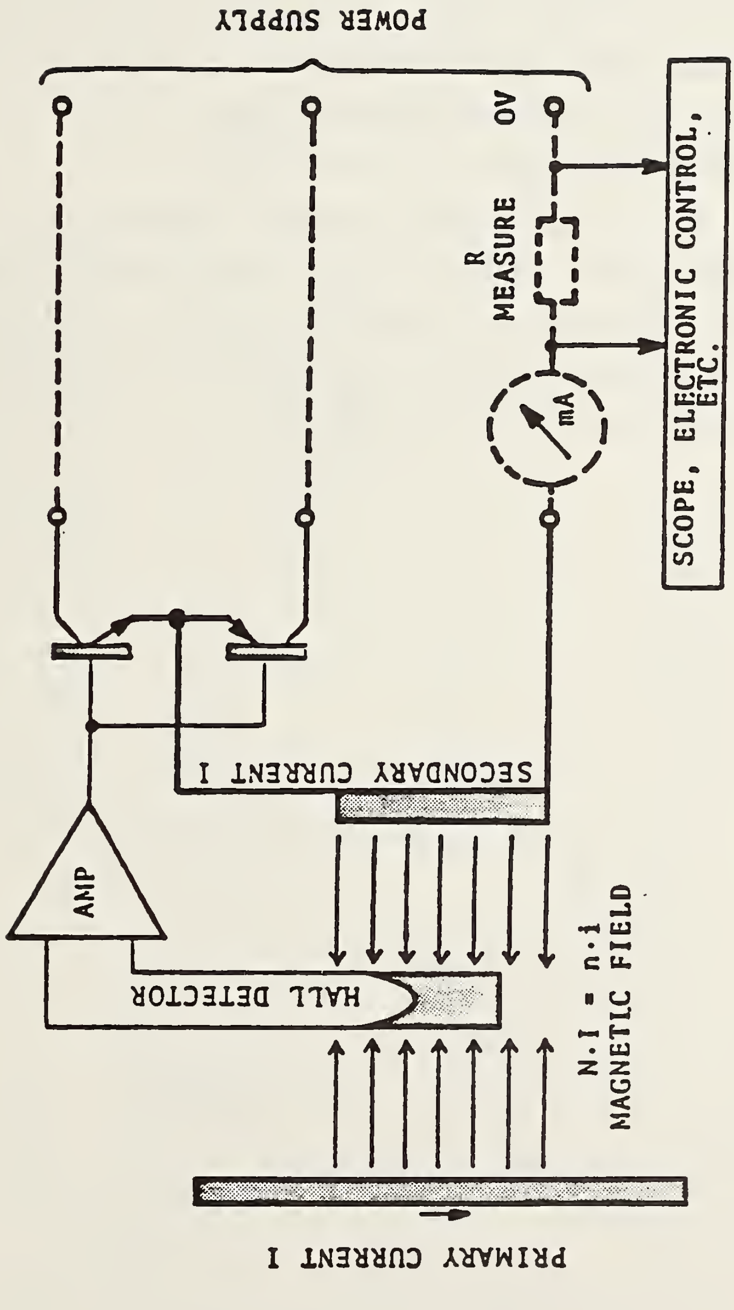


FIGURE RT/CE02A-1. LEM TRANSFOSHUNT

An elementary schematic of the complete instrumentation is shown in Figure RT/CE02A-A-2. The Transfoshunt is placed in the propulsion positive feed line, with the preamplifier-line driver nearby. A 4-pole Butterworth filter is used to split the signal into two frequency ranges in order not to exceed the dynamic range capability of the tape deck and, on occasion, of the spectrum analyzer. In the latter event, each test is performed twice: once without the filter, and once with the filter at the spectrum analyzer input. The audio oscillator is used for spot calibration and checkout of the equipment.

NOTE: The harmonic distortion produced by the test equipment has not been fully characterized. Such distortion can lead to the perception of higher emissions than actually produced. However, the harmonic distortion of the test equipment has been determined to be sufficiently low to permit specification compliance testing to a specified emission level of 17 mA.

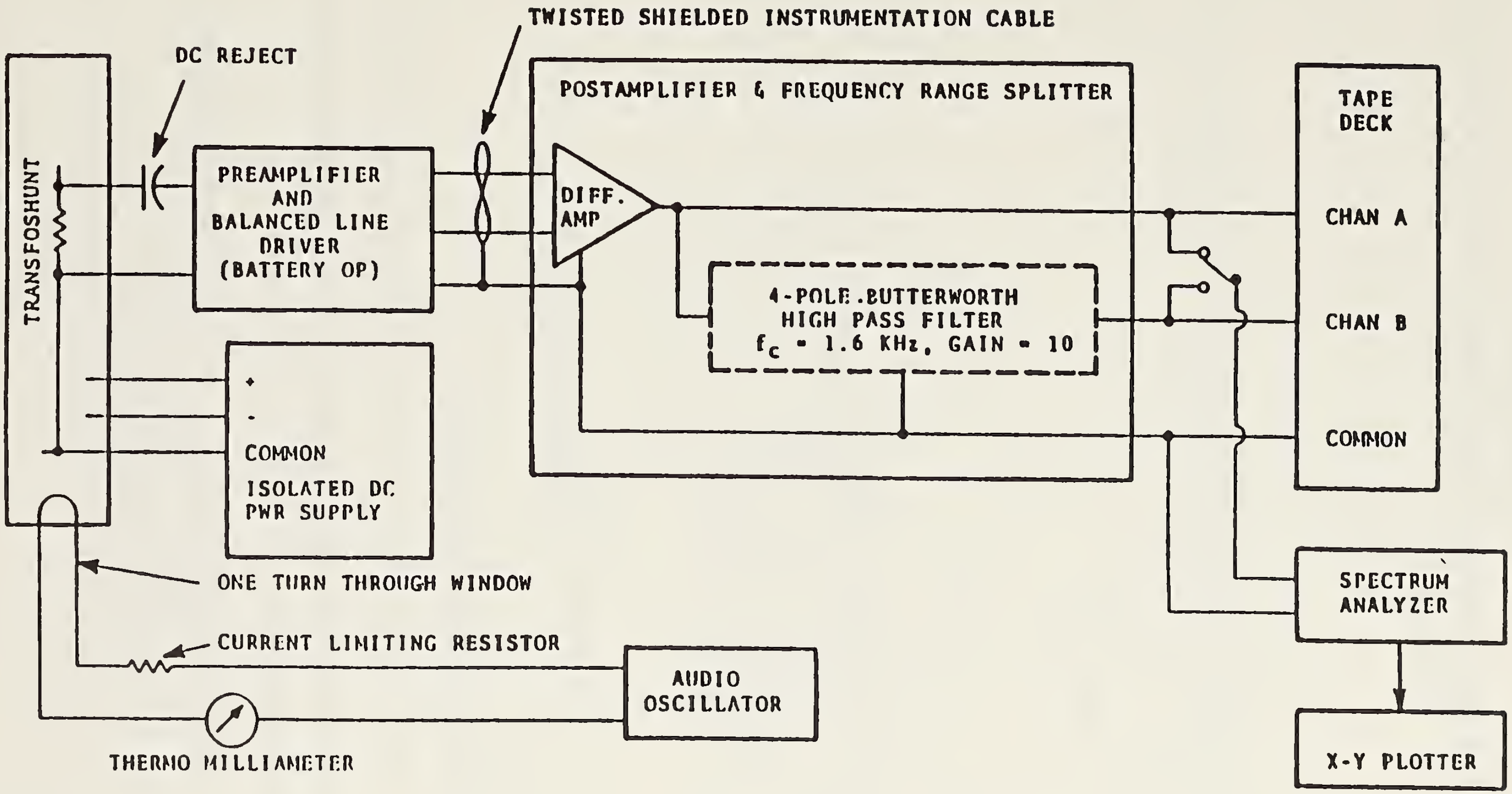


FIGURE RT/CE02A-A-2. ELEMENTARY INSTRUMENTATION SCHEMATIC FOR CONDUCTIVE EMISSION TEST

METHOD RT/OC01A

AUDIO FREQUENCY RATE-CODED TRACK CIRCUIT RECEIVER OPERATING CHARACTERISTICS FROM 300 Hz to 10 kHz

1. PURPOSE

The purpose of this test is to determine the operating characteristics of audio-frequency rate-coded track circuit receivers. Reference point is the rail interface. Resulting information is for use in assessing susceptibility of track circuits to interference.

2. APPLICATION

This method is applicable to all audio frequency track circuit equipment operating at frequencies between 300 Hz to 10 kHz in which the operating signal waveform consists of amplitude-modulated single-frequency tones modulated at a selectable rate (i.e., code rate). This method has been successfully applied and an example is presented in Appendix B.

3. APPARATUS

The apparatus shall include the following:

a. Oscilloscope

b. True RMS audio-frequency voltmeter

c. Wavetek modulated function generator Model 146 or equivalent

d. Phase Linear Model 400 audio-frequency power amplifier or equivalent

e. Frequency counter

f. Audio-frequency network analyzer, HP Model 3582A, or equivalent

g. X-Y plotter compatible with network analyzer

h. Two current probes

4. TEST PROCEDURE

To evaluate the susceptibility of audio-frequency signaling systems to interference, it is necessary to determine the following track circuit receiver operating characteristics at the rail interface:

a. Frequency selective input sensitivity

b. Input impedance

4.1 Verification of Nominal Track Circuit Operation

Verify, according to track circuit manufacturer's instructions, that the track circuit receiver is properly tuned and adjusted. Apparatus shall be as per manufacturer's specifications. Items to be verified include, but are not limited to:

a. Tuning of resonant track coupling units

b. Adjustment of variable receiver sensitivity levels

c. Verification of proper value of transmission line compensation capacitor

For purposes of this test, in those cases where the receiver sensitivity level is adjustable in the field (e.g., by means of a variable potentiometer or switch, as opposed to selection of soldered-in components), the receiver sensitivity level shall be set at its most sensitive level. This sensitivity level will be maintained for the entire test.

4.2 Frequency-Selective Input Sensitivity Test

4.2.1 Test Setup - Assemble the apparatus as shown in Figure RT/OC01A-1.

4.2.2 Transmitter Output Impedance

To properly account for the effects of transmitter output impedance on circuit tuning, the transmitter's output impedance must be included in the circuit while the transmitter output is disabled. The transmitter output is disabled by removing the track signal and train signal oscillator boards from the track circuit module's card file. This method works when the transmitter output impedance is the same under driven and undriven conditions.

4.2.3 Determination of Code Rates

The lowest normally used code rate is the minimum code rate. The highest normally used code rate is the maximum code rate. Determine the normally used

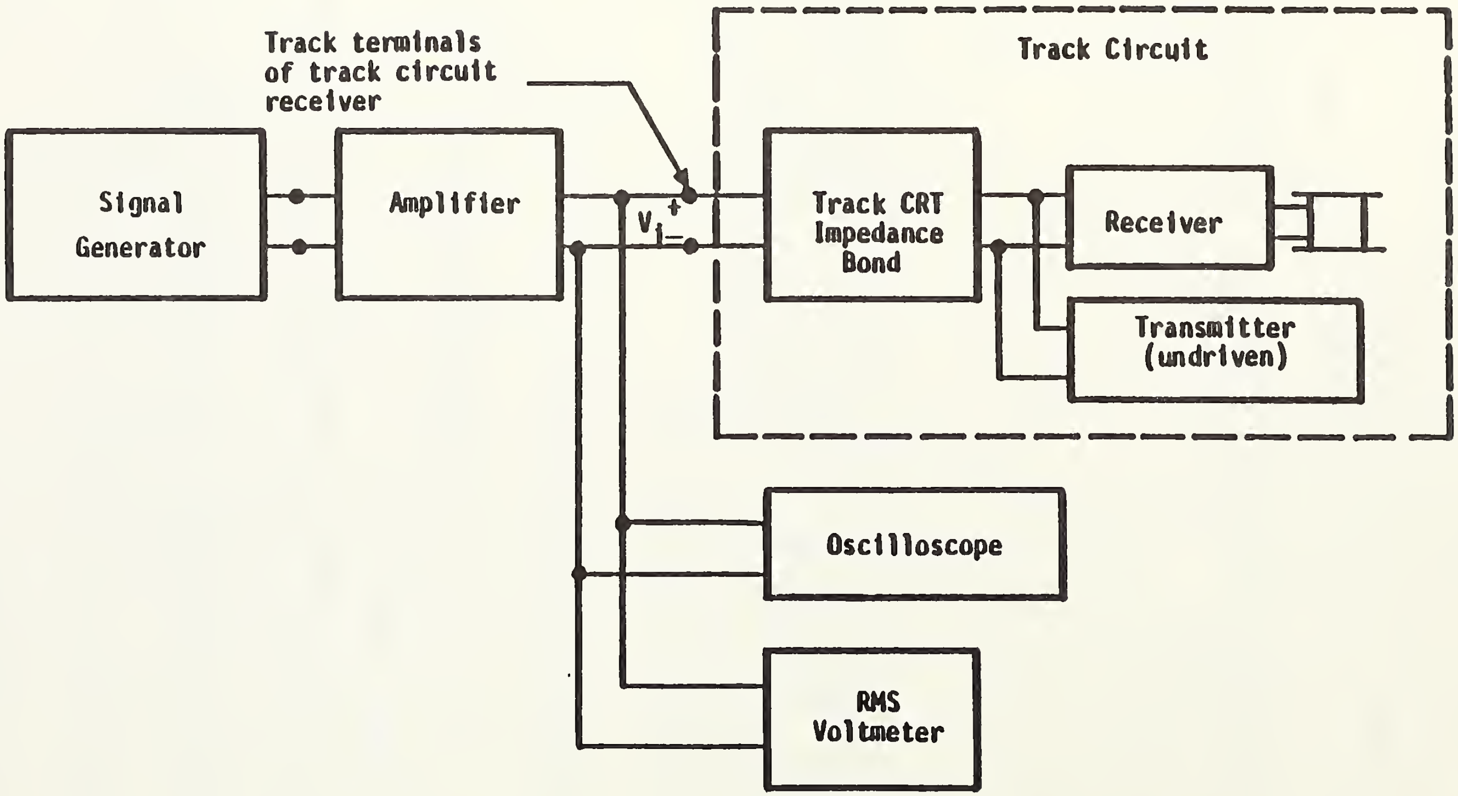


FIGURE RT/OC01A-1. ARRANGEMENT OF TEST APPARATUS FOR MEASURING FREQUENCY SELECTIVE INPUT SENSITIVITY AT TRACK TERMINALS OF TRACK CIRCUIT RECEIVER

code rate which is the closest to the geometric mean of the minimum and maximum code rates (i.e., the normally used code rate) nearest in value to

$$\left[(\text{minimum code rate}) \times (\text{maximum code rate})\right]^{1/2} .$$

This is the intermediate code rate.

4.2.4 Determination of Test Frequency Increment Δf

Using the maximum code rate and square-wave modulation, determine the carrier frequency ranges from 300 Hz and 10 kHz over which the track relay picked up for a signal level less than or equal to 0.5 Vrms (1.4 Vpp). The frequency range that contains the specified operating frequency is the principal frequency range. Other frequency ranges that may exist are subsidiary frequency ranges. The lowest frequency of the principal frequency range is f_1. The highest frequency of the principal frequency range is f_2. (Care must be taken not to apply signals that exceed the manufacturer's recommended maximum levels within the principal frequency range, or equipment may be permanently damaged.) Determine the frequency increment Δf by rounding the value $(f_2 - f_1)/16$ to the next highest number divisible by 5 Hz.

4.2.5 Conditions for Relay Pickup at Operating Frequency

With the signal generator operating CW, adjust its frequency to the specified operating frequency of the track circuit receiver. Square-wave modulate the test signal at the minimum code rate. Adjust the modulation to 100 percent. Slowly increase the level until the track relay picks up. Then, to measure amplitude, switch modulation to CW, and record the rms signal level at the track terminals.

4.2.6 Conditions for Relay Pickup Below Operating Frequency

Repeat 4.2.5 using frequencies Δf, $2\Delta f$, $3\Delta f$, etc., below the specified operating frequency until the lower limit of the principal frequency range f_1 is reached.

4.2.7 Conditions for Relay Pickup Above Operating Frequency

Repeat 4.2.5 using carrier frequencies Δf, $2\Delta f$, $3\Delta f$, etc., above the specified operating frequency until the upper limit of the principal frequency range f_2 is reached.

4.2.8 Test in Subsidiary Frequency Ranges

Repeat 4.2.5 at all frequencies lying in the subsidiary frequency ranges that are spaced from the specified operating frequency by integral multiples of Δ f.

4.2.9 Test at Intermediate and Maximum Code Rates

Adjust the code rate to intermediate code rate and repeat 4.2.5-4.2.8. Then adjust the code rate to the maximum code rate and repeat 4.2.5-4.2.8.

4.3 Input Impedance Test

The impedance characteristics versus frequency of a track circuit can be obtained as follows:

An audio-frequency network analyzer, an audio-frequency power amplifier, and an X-Y plotter are arranged as shown in Figure RT/OC01A-2. The analyzer's white noise generator output is applied through the power amplifier to the input terminals of the impedance bond. The track circuit's transmission line compensating capacitor must be adjusted as per manufacturer's specifications.) As shown in Figure RT/OC01A-2, the current through a 1-ohm reference resistor and the current into the track circuit are measured using matched current probes. The complex ratio of these currents is measured by the analyzer, and the impedance plot is thus obtained.

5. TABULATION OF RESULTS

5.1 Frequency Selective Input Sensitivity Test

Tabulate data on a sheet or sheets as shown in Figure RT/OC01A-3.

5.2 Input Impedance Test

Annotate the plot of input impedance vs. frequency from the network analyzer and plotter as shown in Appendix B.

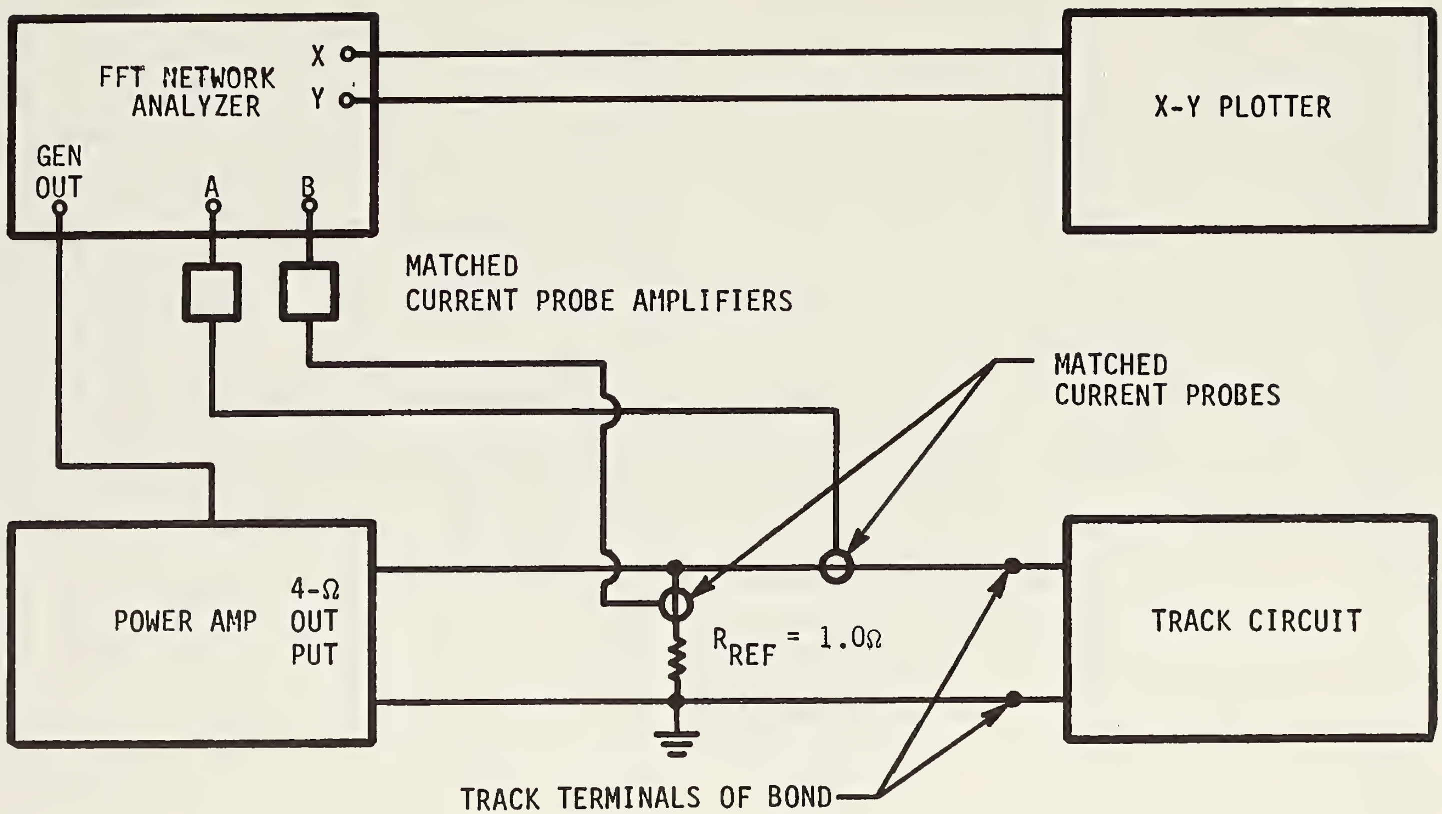


FIGURE RT/OC01A-2. INPUT IMPEDANCE TEST SETUP

System Tested: ____________

Test Performed: ____________

Date: ____________

OPERATING FREQUENCY f_0 = Hz

MAXIMUM CODE RATE = Hz

INTERMEDIATE CODE RATES = Hz

MINIMUM CODE RATE + Hz

* - DENOTES THAT NO VALUE OF V_i LESS THAN 0.5 VRMS (1.4 VP-P) CAUSED TRACK RELAY TO PICK UP

THRESHOLD VALUES OF V_i FOR WHICH TRACK RELAY PICKS UP IN MV RMS																		
Frequency																		
MIN. CODE RATE																		
INTERMEDIATE CODE RATE																		
MAX. CODE RATE																		

NOTES:

FIGURE RT/OC01A-3. SAMPLE DATA TABLE

APPENDIX A

DEFINITIONS AND SYSTEMS OF UNITS

1. SCOPE - This section provides standard definitions and a system of units for the suggested test procedures.

2. GENERAL INFORMATION

2.1 Definitions - Definition of terms used in these test procedures shall be determined by using the references in the order specified below:

a. Section 3 (next section)
b. MIL-STD-463A
c. IEEE Standard Dictionary (Second Edition, 1977)

2.2 System of Units - System of units shall conform to IEEE standards.

3. DEFINITIONS

CODE RATE - The frequency at which the track circuit signal is modulated.

EMMISION, CONDUCTIVE - Desired or undesired current flowing from a source along an ohmic path.

EMISSION, INDUCTIVE - Desired or undesired magnetic flux which is propagated through space.

FLUX MAPPING - The process of determining the spatial distribution of a magnetic field emanating from a source.

FREQUENCY, TRACK CIRCUIT - The frequency of a sinusoidal audio-frequency signal occurring during the on-portion of the code-rate cycle.

INTERFERENCE, CONDUCTIVE - Interference caused by current flowing through a common ohmic path between the emission source and the susceptible circuit.

INTERFERENCE, INDUCTIVE - Interference caused by inductive emissions.

RAIL-TO-RAIL VOLTAGE - The voltage occurring at a point on one rail with respect to the opposing point on the adjacent rail.

SUSCEPTIBILITY, CONDUCTIVE - The degree to which equipment, together with all conductors associated with its intended function, evidences undesired end responses caused by conductive emissions to which it is exposed.

SUSCEPTIBILITY, INDUCTIVE - The degree to which equipment, together with all conductors associated with its intended function, evidences undesired end responses caused by inductive emissions to which it is exposed.

SUSCEPTIBILITY THRESHOLD - Limiting characteristics of an interfering signal which caused an undesired response under defined operating conditions.

TRACK CIRCUIT, AUDIO-FREQUENCY - A train detection and communication scheme generally operating above 300 Hz using the rails as the transmission link. These track circuits do not require, but may use insulated joints to establish their boundaries, and are, in rail transit applications, generally less than 2000 feet in length. Also, they generally operate at receiving-end current levels of less than 1.0 amperes.

TRACK CIRCUIT, POWER FREQUENCY - A train detection and communications scheme operating in the 0 to 300 Hz range using the rails as the transmission link. These track circuits require the use of insulated joints to provide the track circuit boundaries, and generally are used where long track circuits are required. Also, they generally operate at current levels in the ampere range.

TRACK CIRCUIT SIGNALING, AUDIO-FREQUENCY - The system employed to vitally control safe train movement, using audio-frequency track circuits. The functions of train detection and train separation control are involved. Cab signaling, overspeed detection, and other ATP related parameters may also be involved.

TRACK CIRCUIT SIGNALING, POWER FREQUENCY - The system employed to vitally control safe train movement, using power frequency track circuits. The functions of train detection and train separation are involved. Cab signaling, overspeed, and other ATP related parameters may also be involved.

VEHICULAR ELECTRICAL POWER SUBSYSTEM - Those transit vehicle devices involved in converting the prime power into forms for utilization by the car, viz., inverters, converters, propulsion controllers, etc.

APPENDIX B

SAMPLE TEST OUTPUTS USING CONDUCTIVE SUGGESTED TEST PROCEDURES

METHOD	EXAMPLE	PAGES
RT/CE01A	MARTA	B-2 - B-3
RT/OC01A	GRS	B-4 - B-7
RT/OC01A	US & S	B-8 - B-11

SYSTEM TESTED: MARTA

FIELD LOCATION: CANDLER PARK SUBSTATION

TEST PERFORMED: RT/CE01A

BY WHOM: R. RUDICH (GARRETT)

COMMENTS:

DATE: 8/26/79

RUN #	INSTRUMENT SETTINGS	SCENARIO
17		SEE PARA 4.0 RT/CE01A 8 CAR

APPARATUS USED: SEE PARA 3.2 RT/CE01A

DIAGRAM: TEST MEASUREMENT

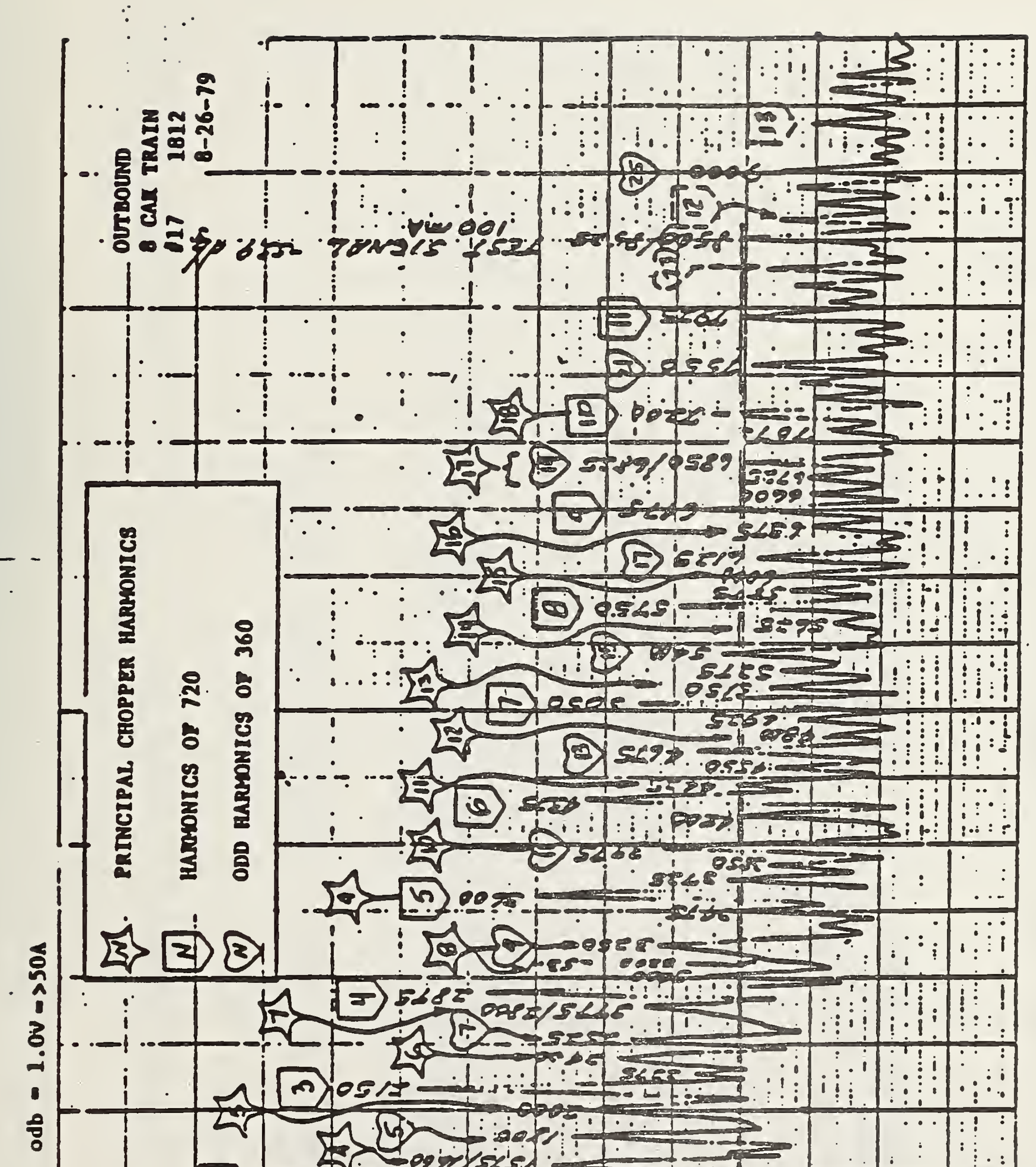
SEE FIGURE RT/CE01A A-2 EXHIBIT

NOTE 1

NOTE 2

NOTE 3

NOTE 4


0db = 1.0V = >50A
OUTBOUND
8 CAR TRAIN
#17 1812
8-26-79
PRINCIPAL CHOPPER HARMONICS
HARMONICS OF 720
ODD HARMONICS OF 360
TEST SIGNAL
100 mA

SYSTEM TESTED: CRS (BRAINTREE EXTENSION)
FIELD LOCATION: MBTA CABOT SIGNAL BLD
TEST PERFORMED: RT/OCO1A FREQUENCY SELECTIVE INPUT
BY WHOM: E. GAGNON & J. CADIGAN (DOT/TSC)
COMMENTS: TRACK CIRCUIT DRAWING #58521-7 (MAINTENANCE TEST UNIT)

DATE: 3/25/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
18	SELECT PROPER CODE RATE AND CARRIER FREQUENCY	SEE PROCEDURE RT/OCO1A PARAGRAPH 4.2

APPARATUS USED: SIGNAL GENERATOR (NOTE 3). AMPLIFIER (McINTOSH 240). FREQUENCY COUNTER (H/P 5327B) RMS VOLTMETER (H/P 3403A). OSCILLOSCOPE (H/P 1701B)

DIAGRAM: TEST MEASUREMENT

S E E   F I G U R E   RT/OCO1A-1 (NOTE 1 AND NOTE 2)

NOTE 1 UNMODULATED TRANSMITTER REPLACED BY 14mh COIL AND 400Ω RESISTOR IN PARALLEL
NOTE 2 0.1 μfd CAPACITOR PLACED ACROSS RECEIVER TERMINALS FOR LINE COMPENSATION
NOTE 3 A ROCKLAND SYNTHESIZER MODEL 5100, MODULATED AT THE CODE RATES, USED IN PLACE OF SPECIFIED SIGNAL GENERATOR.

SYSTEM TESTED: GRS (BRAINTREE EXTENSION) BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

TEST PERFORMED: RT/OCO1A FREQUENCY SELECTIVE INPUT WHERE: MBTA CABOT SIGNAL BLD

DATE: 3/25/80

VIS = INTERFERENCE SUSCEPTIBILITY LEVEL IN MVrms

OPERATING FREQUENCY: F_0 = 3060Hz

CODE										F_0									
RATE HZ			2710	2760	2810	2860	2910	2960	3010	3060	3110	3160	3210	3260	3310	3360	3410	3460	
1.25						Δ	292	39.5	32.1	27.2	28.5	33.0	230	Δ					
3.0						Δ	265	36.8	31.3	26.9	28.2	32.8	221	451	Δ				
6.83			Δ	494	401	332	148	38.4	32.2	26.2	27.7	32.6	114	236	293	343	445	Δ	

Δ NO PICK OF RELAY AT 0.5 VRMS

FIELD

SYSTEM TESTED: CRS (BRAINTREE EXTENSION) LOCATION: MBTA CABOT SIGNAL BLD

TEST PERFORMED: RT/OC01A INPUT IMPEDANCE BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

COMMENTS: RECEIVER OPERATING FREQUENCY = 3060 Hz

TRACK CIRCUIT DRAWING #58521-7 (MAINTENANCE TEST UNIT) DATE: 4/1/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
38	CAREFULLY SET SENSITIVITY LEVELS OF CHANNELS A & B OF SPEC. ANAL. PER INSTRUCTION MANUAL	SEE RT/OC01A PARAGRAPH 4.3

APPARATUS USED: SPECTRUM ANALYSER (H/P 3582A), TEKTRONIX P-6019 PROBES & 134 AMPLIFIERS, X-Y PLOTTER (EATERLINE ANGUS MODEL 575), AMPLIFIER (McINTOSH - MC-240

DIAGRAM: TEST MEASUREMENT

S E E F I G U R E RT/OC01A-3 (NOTE 1 AND NOTE 2)

NOTE 1 UNMODULATED TRANSMITTER REPLACED BY 14 mh COIL AND 400Ω RESISTOR in PARALLEL

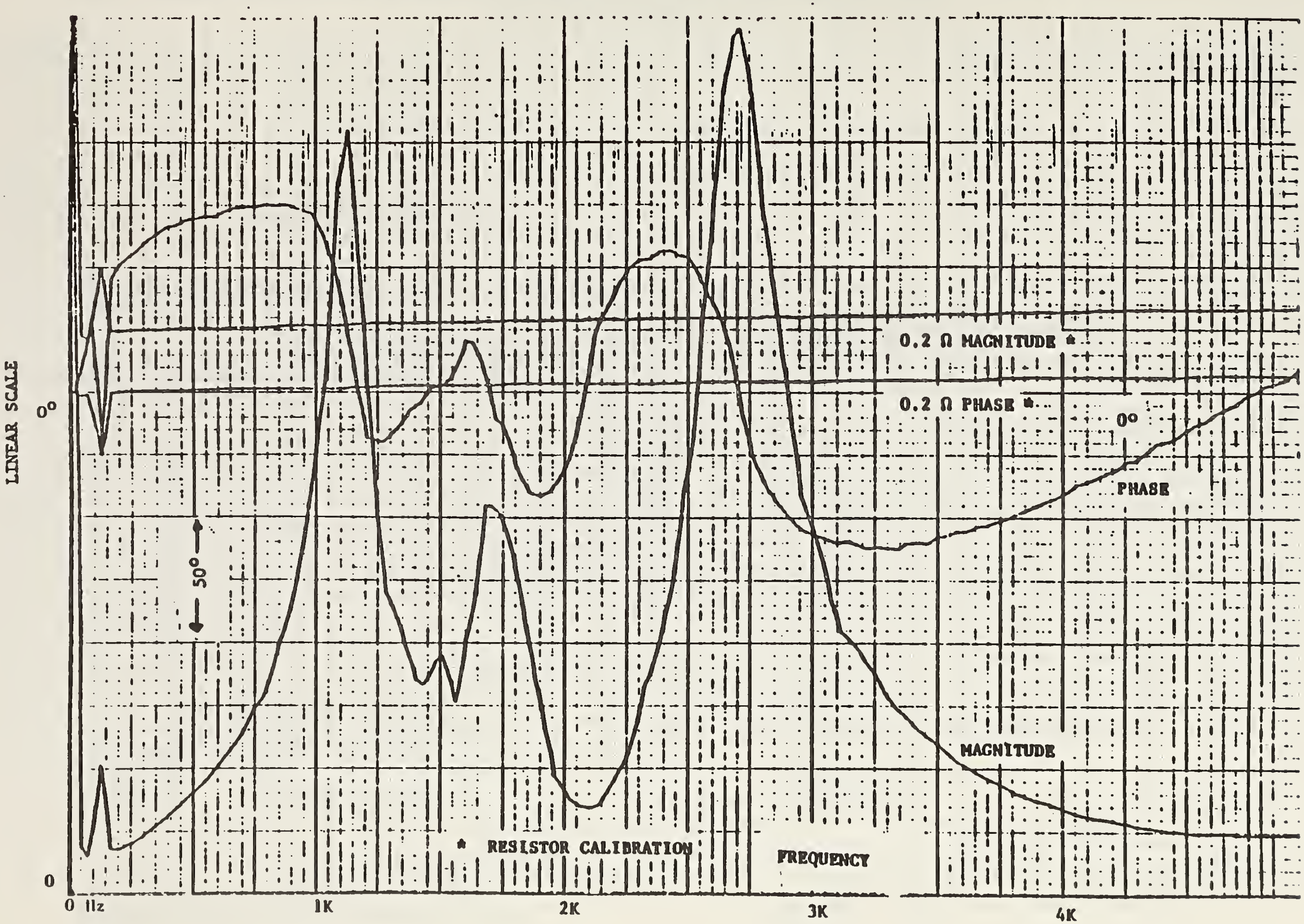
NOTE 2 0.1 μfd CAPACITOR ...ACED ACROSS RECEIVER TERMINALS FOR LINE COMPENSATION

NOTE 3

NOTE 4

SYSTEM TESTED: US & S (HAYMARKET NORTH)
TEST PERFORMED: RT/OCO1A INPUT IMPEDANCE
RECEIVER OPERATING FREQUENCY: 1590 Hz

FIELD LOCATION: MBTA CABOT SIGNAL BLDG
BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)
DATE: 3/31/80



SYSTEM TESTED: US&S (Haymarket North)

FIELD

LOCATION: MBTA Cabot Signal Building

TEST PERFORMED: RT/OC01A Frequency Selective Input

BY WHOM: R. Gagnon & J. Cadigan (DOT/TSC)

COMMENTS: Track Circuit AF-200

DATE: 3/25/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
23	Select Proper Code Rate and Carrier Frequency	See Test Method RT/OC01A Procedure Para. 4.2

APPARATUS USED: Signal Generator (Note 1), Amplifier (McIntosh-MC240), Frequency Counter (H/P 5327B), RMS Voltmeter (HIP3403A), Oscilloscope (H/P1701B)

DIAGRAM: TEST MEASUREMENT

See Figure RT/OC01A-1

NOTE 1 Rockland Synthesizer Model 5100 Modulated at the Code Rates was used in place of specified Signal Generator

NOTE 2

NOTE 3

SYSTEM TESTED: US&S (Haymarket North)
TEST PERFORMED: RT/OCO1A Frequency Selective Input
DATE: 3/25/80

BY WHOM? R. Gagnon & S. Cadigan (DOT/TSC
WHERE: MBTA Cabot Signal Boulevard

VIS = INTERFERENCE SUSCEPTIBILITY LEVEL IN MVrms

OPERATING FREQUENCY: F_O = 1590

CODE RATE HZ				1470	1490	1510	1530	1550	1570	F_O 1590	1610	1630	1650	1670	1690	1710	1730		
5.0					Δ	411	249	102	74.5	70.2	78.1	162	335	461	Δ				
10.8				Δ	474	329	203	98.1	69.1	65.4	74.2	139	253	345	439	Δ			
20.4				Δ	498	329	208	103	71.7	63.0	78.0	143	255	328	450	490	Δ		

Δ No pick of relay at 0.5 VRMS

SYSTEM TESTED: US&S (Haymarket North)　　FIELD LOCATION: MBTA Cabot Signal Bldg

TEST PERFORMED: RT/ OC01A Input Impedance　　BY WHOM: R. Gagnon & S. Cadigan (DOT/TSC)

COMMENTS: Receiver Operating Frequency = 1590 Hz

Track Circuit AF-200　　DATE: 3/31/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
43	Carefully set sensitivity levels of Channels A&B of Spec Anal. per Instruction Manual	See RT/OC01A Paragraph 4.3

APPARATUS USED: Spectrum analyzer (H/P 3582A). Tek Tronix P-6019 Probes & 134 Amplifiers. X-Y Plotter (Esterline Angus Model 575). Amplifier (McIntosh-MC240)

DIAGRAM: TEST MEASUREMENT

See Figure RT/OC01A-3 (Note 1)

NOTE 1 Include Unmodulated Transmitter as in RT/OC01A Procedure Para 4.2

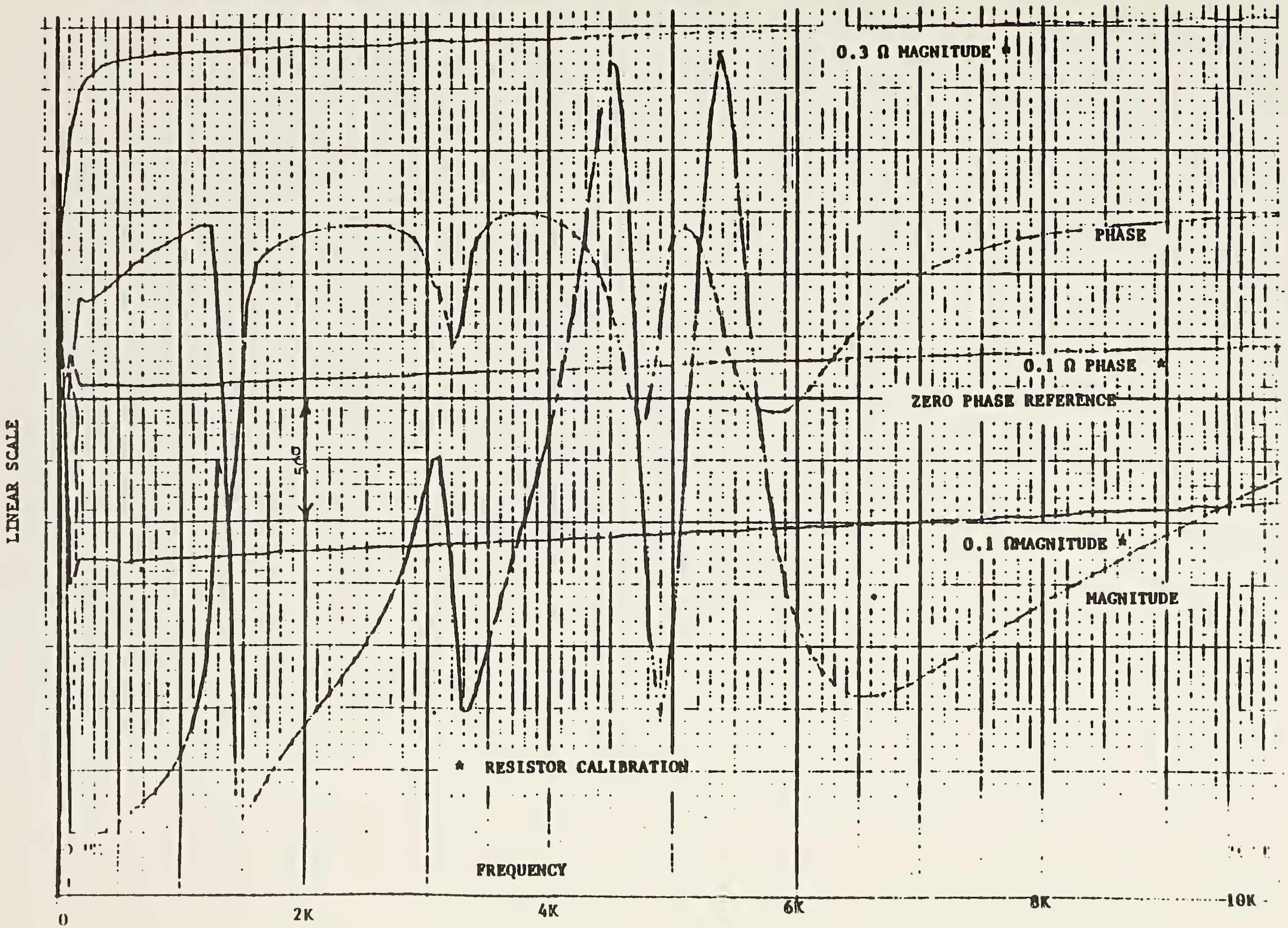
NOTE 2

NOTE 3

NOTE 4

SYSTEM TESTED: GRS (BRAINTREE EXTENSION)
TEST PERFORMED: RT/OCO1A INPUT IMPEDANCE
RECEIVER OPERATING FREQUENCY: 3060 Hz

FIELD LOCATION: MBTA CABOT SIGNAL BLDG
BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)
DATE: 4/1/80



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